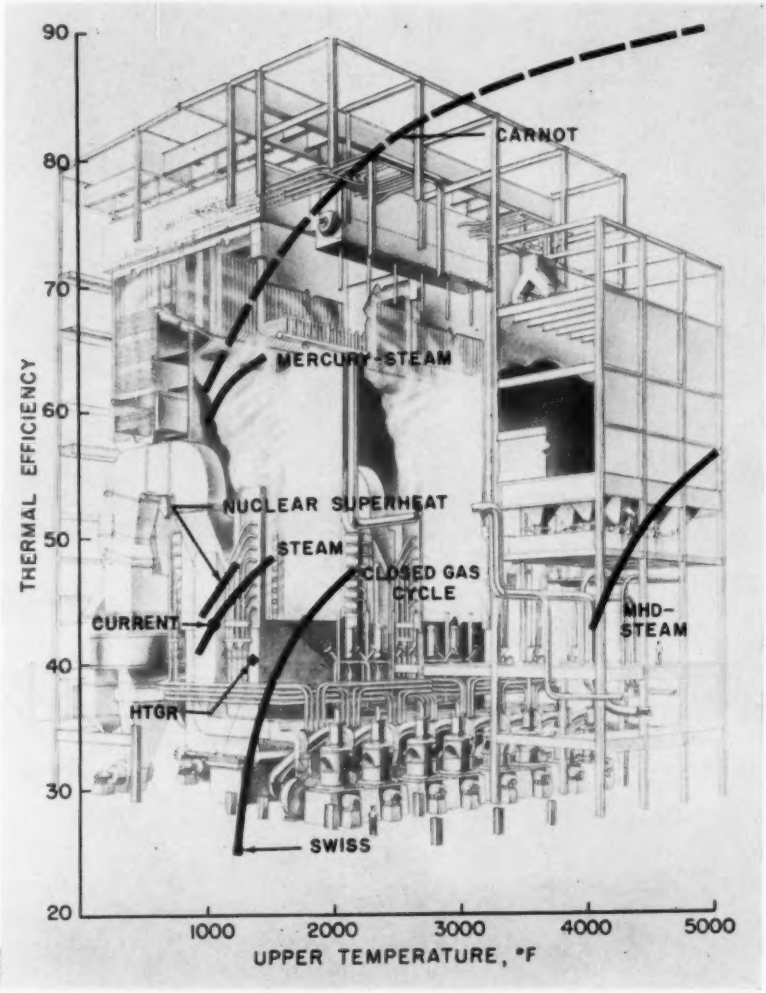
Combustion

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION



October 1961

MHD Power Generation Methods

A Field Probe for Flue Gas Deposits

Repeated Acid Cleaning

Launching USS SEMMES at
Avondale Shipyards, Inc., Avondale, La.

USS SEMMES

one of five new Guided Missile Destroyers to be powered by

C-E V2M VERTICAL SUPERHEATER BOILERS

Almost a third larger than destroyers of World War II, these new DDG's will have better seakeeping qualities and a longer cruising range. They will act as screen units for task forces and convoys, work with hunter-killer groups, and support amphibious operations. Each will be equipped with 4 C-E Vertical Superheater Boilers.

The C-E V2M Vertical Superheater Boiler offers maximum protection against slagging by eliminating slag-collecting, horizontal tubes. Parallel superheater tubes and generating tubes provide more effective soot-blowing. Fewer manual cleanings reduce maintenance costs. Since vertical superheater tubes permit supports to be outside of the gas pass, the expensive maintenance associated with any type of fire-side support is eliminated. For inspections and routine maintenance, excellent accessibility is provided throughout the boiler.

COMBUSTION ENGINEERING

C-335

General Offices: Windsor, Conn.
New York Offices: 200 Madison Ave., New York 16, N. Y.
Canada: Combustion Engineering-Superheater Ltd.

ALL TYPES OF STEAM GENERATING, FUEL BURNING AND RELATED EQUIPMENT; NUCLEAR REACTORS; PAPER MILL EQUIPMENT; PULVERIZERS; FLASH DRYING SYSTEMS; PRESSURE VESSELS; SOIL PIPE

Combustion

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

volume 33 number 4 **October 1961**

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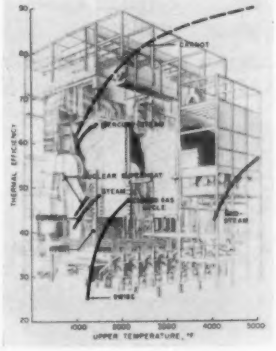
COVER PHOTO

Superimposed on a wash drawing of a large operating boiler we have placed the efficiency curves of our known thermal, nuclear, MHD means of generating power



A Probe for Studying Deposition of Solid Material from Flue Gas at High Temperatures . . . 22

P. J. Jackson

Because no laboratory mock-up can approach the actual field conditions between boiler heat transfer surfaces and the fuel and flue gas exposed to them a practical, robust probe has been developed for field duty and field studies.

Removal of Slag Deposits from Screen Type Superheaters by Vibration Methods . . . 29

L. G. Kropp and D. L. Itman

The constant search for extending equipment availabilities have led the Russians to investigate vibration methods of cleaning superheater surfaces. Here is a how-to story.

Repeated Acid Cleaning of Boilers . . . 35

The July issue of COMBUSTION carried a paper by J. K. Rice in which he raised certain points and made some tentative conclusions. Eight very active men in the field of water conditioning had pungent comments to make. We print them all here together with Mr. Rice's closure.*

Magnetohydrodynamic Power and Propulsion . . . 44

George W. Sutton and Per Gloersen

For the first time to our knowledge some of the parameters affecting MHD are spelled out in dimension form. The problems and the hopes are equally and ably stated. We confined them to bulk power applications.

Abstracts from the Technical Press—At Home and Abroad . . . 52

Editorial: Progress and the Turnkey Contract . . . 21

Advertising Index . . . 58–59

Burner flame on?

New FLĀMON Detector

can help you be sure!

Two FLĀMON Detectors installed for independent monitoring of main burner flame and pilot flame of a gas-fired boiler.

Properly installed, the FLĀMON Detector *responds only to the flame it surveys.* Glowing refractories—or flames from adjacent burners—do not produce false signals. Positive monitoring of each burner is assured. Absence or failure of flame is sensed and accurately signaled—and transmitted to control auxiliaries—without use of external relays or amplifiers.

Key to automation . . . the FLĀMON Detector provides the key to reliable automatic light-off and shutdown.

Provides wide temperature range . . . the FLĀMON Detector can be used in ambient temperatures from −20 to 150°F. Flame-sensing element withstands temperatures up to 500°F.

Allows easy inspection . . . quick-disconnect, keyhole mounting simplifies checking of lens condition and detector alignment.

Simple, solid-state circuitry . . . the FLĀMON Detector unit contains only 10 components.

Weatherproof construction . . . design of Bailey unit makes it suitable for outdoor installation.

Your local Bailey Engineer can give you a demonstration of the FLĀMON Detector. Call him, or write Cleveland.

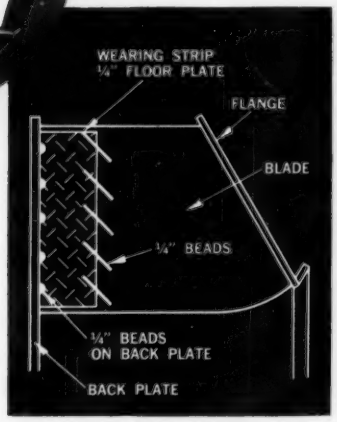
A 162-1

Instruments and controls for power and process

BAILEY METER COMPANY

1025 IVANHOE ROAD • CLEVELAND 10, OHIO

In Canada—Bailey Meter Company Limited, Montreal



Designed for the most rugged induced draft applications, 'Buffalo' Type "H" Fans withstand continuous abrasive wear at the highest static efficiency ever obtained with this type fan. ■ Radial tip blades curve smoothly forward at the heel to meet incoming air at the optimum angle. A modified flange design produces streamlined flow of air from wheel entrance to tips of the blades. Welded wear strips (¼" steel floor plate) break up particle flow and prevent dust particles from gouging or scouring the blades. ■ Particle buildup is eliminated... housing wear is negligible... turbulence is minimized. In addition, static pressure and capacity are increased... maintenance costs and sound levels lowered. ■ 'Buffalo' Type "H" Fans are available in 15 sizes and a variety of widths for various capacity/pressure requirements. ■ For all the facts, call the resident Buffalo representative nearest you. Or write our home office direct.

AIR HANDLING DIVISION

BUFFALO FORGE COMPANY

Buffalo, New York

Canadian Blower & Forge Co., Ltd., Kitchener, Ont.

'Buffalo' Air Handling Equipment to move, heat, cool, dehumidify and clean air and other gases.

'Buffalo' Machine Tools to drill, punch, shear, bend, slit, notch and cope for production or plant maintenance.

'Buffalo' Centrifugal Pumps to handle most liquids and slurries under a variety of conditions.

Squier Machinery to process sugar cane, coffee and rice. Special processing machinery for chemicals.

THE LARGEST VACUUM FLASH EVAPORATORS IN THE WORLD, TO BE BUILT BY RICHARDSONS, WESTGARTH & CO. LIMITED

The Government of Curaçao has awarded to Richardsons, Westgarth & Co. Limited a contract for two vacuum flash evaporators, each capable of producing from sea water 1,400,000 Imperial gallons of drinking water a day. These will be the largest evaporators ever built.

Richardsons Westgarth, pioneers of the vacuum flash evaporator in Great Britain, now have in operation or on order:

- Vacuum flash evaporators with the largest individual output in the world.
- Vacuum flash evaporators producing the largest total combined output of fresh water in the world.
- More land based vacuum flash evaporators than any other manufacturer.

With plant in operation in Great Britain, South America and many parts of the Middle East, Richardsons Westgarth experience in this highly specialised field is at the disposal of all who require supplies of fresh water for domestic or industrial use.

Consultants for this contract are Stichting Nederlands Adviesbureau Voor Ingenieurswerken in Het Buitenland, The Hague, in association with Tebodin, Advies-en-Constructionbureau NV., The Hague.

RICHARDSONS, WESTGARTH & CO. LIMITED

The controlling Company of the RICHARDSONS WESTGARTH GROUP,
Wallsend, Northumberland, England.
In the U.S.A. and Canada: Richardsons Westgarth Inc. 1926 Eye Street, N.W., Washington 6, D.C, U.S.A., Telephone: Federal 82868

RW93

YARWAY news briefs

from **Yarnall-Waring Company,** *Philadelphia 18, Pa.*

BRANCH OFFICES IN 19 UNITED STATES CITIES • SALES REPRESENTATIVES THROUGHOUT THE WORLD

PROVEN DEPENDABILITY

MORE THAN 16,000 INSTALLATIONS ATTEST TO SUCCESS OF YARWAY REMOTE LIQUID LEVEL INDICATORS

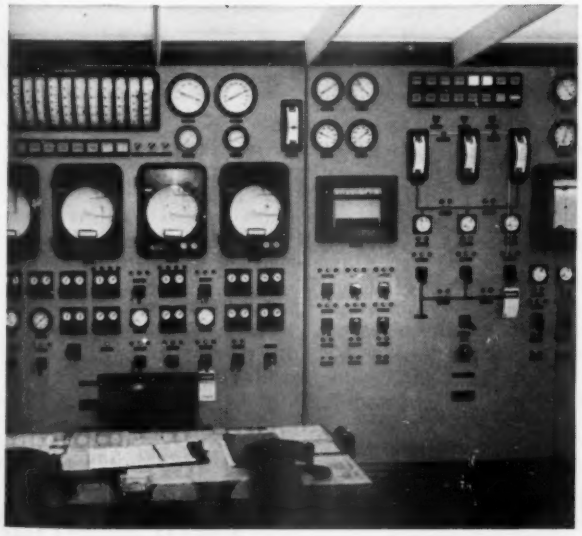
Widespread use of remote liquid level indicators for boiler water level applications, many within ASME Boiler Code requirements as they pertain to installations over 900 psi, have focused attention on the outstanding service record of Yarway Indicators.

More than 16,000 Yarway Remote Liquid Level Indicators are in successful service throughout industry — hundreds are operating in place of one of two required gage glasses on higher pressure boilers as permitted by the code.

Briefly, these features are responsible for Yarway Indicator's dependability—and success:

- Readings are *instant* and *accurate* because indicator is operated by the boiler water itself
- Pointer mechanism is never under pressure
- Brilliant, wide-vision dial makes readings easy from any point in a 180° arc around the indicator—and at considerable distances

Write for Bulletin RI-1825 (pressures to 700 psi), or Bulletin RI-1826 (over 700 psi).



Four Yarway Remote Liquid Level Indicators installed at new Mid-West utility.

A FEW TYPICAL USERS

INDUSTRIAL PLANTS

WEYERHAEUSER COMPANY
REPUBLIC STEEL CORP.
FORD MOTOR COMPANY
UNION BAG & PAPER COMPANY
WESTINGHOUSE ELECTRIC CORP.
GENERAL ELECTRIC COMPANY
STAUFFER CHEMICAL COMPANY
WILSON & COMPANY
U. S. STEEL COMPANY
GENERAL MOTORS
MOBIL OIL COMPANY

UTILITIES

COMMONWEALTH EDISON
IOWA ILLINOIS GAS & ELECTRIC
CENTRAL ILLINOIS PUBLIC SERVICE
ILLINOIS POWER CO.
WISCONSIN POWER & LIGHT
CONSUMERS POWER CO. (JACKSON, MICH.)
NORTHERN STATES POWER CO.
PUBLIC SERVICE OF INDIANA
INDIANAPOLIS POWER & LIGHT
IOWA ELECTRIC LIGHT & POWER
NEBRASKA POWER
NEW ENGLAND POWER
ROCHESTER GAS & ELECTRIC CO.
PENNSYLVANIA ELECTRIC CO. (ERIE, PA.)
OMAHA PUBLIC POWER DISTRICT
CENTRAL ILLINOIS GAS & ELECTRIC
NARRAGANSETT ELECTRIC CO.
LOUISIANA POWER & LIGHT
HARTFORD ELECTRIC LIGHT CO.
POTOMAC ELECTRIC POWER CO.

Compact Packaged Air Preheater being unloaded for installation on new 100,000 lb/hr boiler at Hoffmann-La Roche's Nutley, N. J. headquarters. In operation, it will increase the temperature of the combustion air 375°F—thereby increasing boiler efficiency by approximately 8%.

PACKAGED AIR PREHEATER

WILL RECOVER 330°F FROM NEW BOILER FOR HOFFMANN-LA ROCHE INCORPORATED

Hoffmann-La Roche, one of the leading producers of pharmaceuticals, vitamins and aromatic chemicals, specified a Ljungstrom Packaged Air Preheater for their new boiler for three reasons: 1) This compact, preassembled unit is ready to run as soon as it's connected to the power line and ducts—no extra installation or erection costs; 2) The unit occupies only about 450 cubic feet of space but will cut boiler exhaust temperatures from 680°F to 330°F—for about 8% saving in fuel; 3) Savings in fuel alone—roughly 1% for every 40°F drop in exit gas temperature—can pay for the unit in two short years!

Packaged Ljungstroms are available in sizes for use on boilers in the 25,000 to 250,000 lb/hr range—can give you these same fuel saving advantages. For full information, write today for our 14-page Packaged Air Preheater booklet.

THE AIR PREHEATER CORPORATION

60 East 42nd Street, New York 17, N. Y.

Avon Lake No. 8 Demands Ultra-High Purity Water . . . and

NALCITE® ION EXCHANGE RESINS DO THE JOB

Cleveland Electric Illuminating Company's Makeup and Condensate Demineralizers Supply Mineral Free Water for the Avon Lake No. 8 Supercritical Steam Generator

It takes a lot of 1100°F steam to run the big, 250 MW turbogenerator at the Cleveland Electric Illuminating Company's Avon Lake plant. Because this steam is generated at a supercritical pressure of 3500 psia, water entering the steam generator *must* be pure—pure enough to meet requirements of a stringency unheard of only a few years ago.

PURE WATER ESSENTIAL FOR SUPERCRITICAL STEAM

Supercritical pressure steam at Avon Lake is generated at a 1,715,000 lb/hr rate in a monotube, or "once-through" boiler-superheater, which is, in effect, a series of heat exchanger tubes. Steam generated above critical pressure of 3205 psig does not form bubbles and separate from water (its density is the same as the water in the boiler). There is no opportunity for concentration and separation of impurities by blowdown. Therefore, water from which supercritical steam is produced must be free of impurities and suspended solids which would otherwise form deposits in the steam generator and turbine.

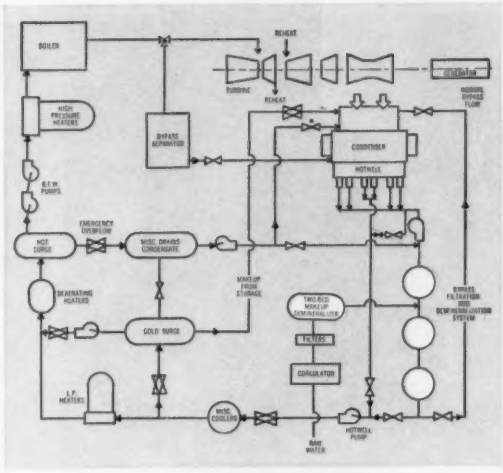
Specifications for the Avon Lake generator call for a maximum of 20 ppb silica, 20 ppb iron, and 10 ppb copper, at the economizer inlet.

CONDENSATE BYPASS DEMINERALIZERS KEEP WATER PURE

Condenser leakage (or "weepage"), corrosion products, auxiliary drains, and makeup water are all sources of contamination—contamination that can cause real trouble in the boiler and turbine. This contamination is controlled in the Avon No. 8 system by three mixed bed demineralizers on the condensate loop. Ionized materials are removed from the steam generator feedwater by three ion exchange beds, two of which contain Nalcite® HCR® and SBR-P®. Suspended matter is removed by pre-coat type filters. The demineralization equipment is generously sized, to provide "dynamic storage" of boiler water, and is capable of handling 100 per cent condensate flow at full turbine load.

EFFECTIVE DEMINERALIZATION FOR HIGH PURITY MAKEUP WATER

Makeup water from Lake Erie is coagulated and filtered, then passed through a standard



Simplified Flow Diagram of Avon Lake No. 8 Supercritical Steam Generating System

two-bed demineralizer containing Nalcite HCR® and Nalcite SBR-P® for removal of dissolved solids. Integral to the demineralizer is a vacuum deaerator for gas removal. The gas-free effluent of the demineralizer is further polished as it passes through the condensate bypass loop demineralizer.

PURITY, CAPACITY, AND DURABILITY

Industrial water demineralization calls for tough, uniform resin beads. Careful production of Nalcite resins holds the number of small beads to a minimum; thus pressure differentials across Nalcite resin beds are kept low. And, Nalcite resins are tough, durable, and long lasting under the roughest of conditions.

Nalcite ion exchange resins are available to help today's—and tomorrow's—engineers meet the demand for purer water at higher temperatures, pressures, and flow rates. For details on cation and anion exchangers offered by Nalco, write for Bulletins Z-12 and Z-13, free on request. For information on water conditioning with Nalcite resins, ask for Bulletin Z-5. If you need a fast, effective solution to a specific water treatment problem, Nalco experts are at your service. Call or write:

NALCO CHEMICAL COMPANY
Ion Exchange Products
6234 West 66th Place • Chicago 38, Illinois
Subsidiaries in England, Italy, Mexico, Spain, Venezuela and West Germany
In Canada: Alchem Limited, Burlington, Ontario

Nalco® . . . **Serving Industry through Practical Applied Science**

Nalco CHEMICALS
Nalco SERVICES

Pneumatic Control Valves—This 20-inch, 400-psig pneumatic piston-operated double-seated control valve was designed and built for back-pressure service in a utility station. Type CV-P valves are recommended for flow- and pressure-control applications demanding the finest valves money can buy. Copes-Vulcan also offers diaphragm-operated valves with wide rangeability and control characteristics tailored for the individual installation.

COPES-VULCAN

Hydraulic Control Valves—This 600-psig hydraulically-operated control valve, with 16-inch inlet, 20-inch outlet and 2½-inch stroke was designed and built for steam-dump in 80 milliseconds and precise back-pressure control. Copes-Vulcan offers valves in sizes up to 20-inch, and in pressure standards up to 2500-psig. They may be single- or double-seated. They can handle pressure drops up to 2000 psig.

Nuclear Valves—This 6-inch, 1500-psig motor-operated three-way selector valve for use in a stationary nuclear power plant was built of stainless steel for primary-fluid relief service. The unique design reflects the engineering capability offered by Copes-Vulcan for the solution of the most difficult problems encountered in both nuclear and conventional power stations.

for today's needs...for tomorrow's planning

Copes-Vulcan offers equipment and control systems for boiler cleaning, combustion, feedwater, desuperheating, pressure reducing, and superheat and reheat steam temperatures. Each is available separately, or as an integral part of a single control package, custom-engineered to meet individual needs.

Copes-Vulcan also offers special valves for applications in conventional and nuclear power plants on land and sea. Like all Copes-Vulcan products, they are backed by experience gained in serving the power industry for more than half a century. Copes-Vulcan Division, Erie 4, Pennsylvania.

Copes-Vulcan Division

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LOOK AT WHAT USERS SAY ABOUT L&N COMPUTERS

System operators who have been using the initial eight L&N solid-state economic dispatch computers for 18 months or longer were asked to rate their machines as either "Excellent" "Good" "Fair" or "Poor" in five respects. Look at the results:

	1	2	3	4	5	6	7	8	TOTALS
1. In view of our original expectations regarding fuel savings and overall effectiveness in handling system regulation, we rate the performance of this computer as:	E	G	E	G	G	E	G	E	4E 4G
2. Reliability of the computer to date has been:	E	E	G	G	G	E	G	E	4E 4G
3. From the standpoint of the operator's convenience, we rate the Desired Generation Computer as:	G	G	E	G	E	E	E	E	5E 3G
4. The readouts, setters and X-Y plotter (if any) are features which we consider:	E	G	E	F	G	*	E	E	4E 2G 1F
5. Installation of the computer, and subsequent check-out procedures were handled in a way which we consider:	E	E	G	E	G	G	E	E	5E 3G
									22E 16G 1F

**Not applicable*

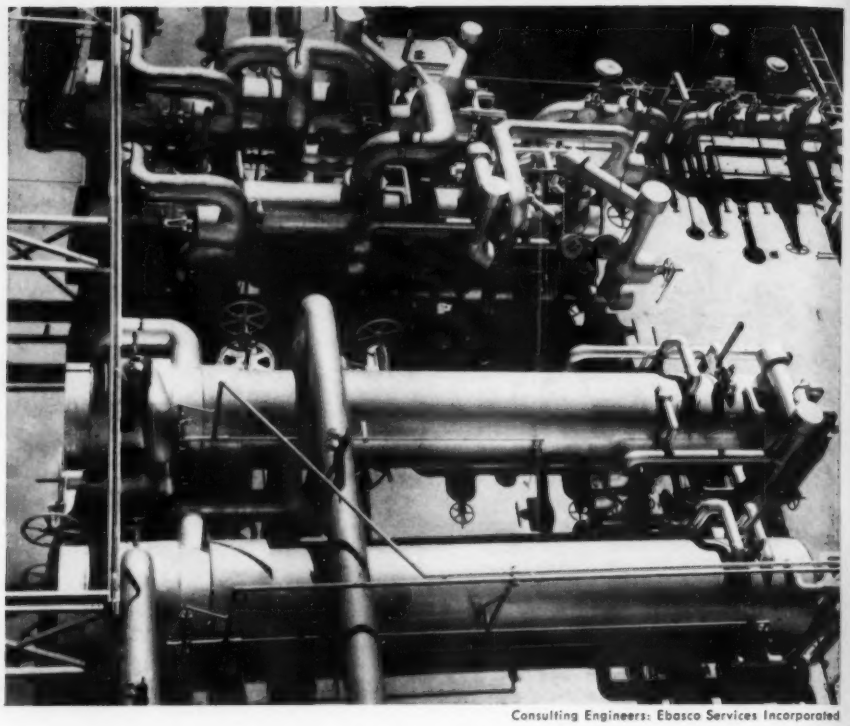
Note that this report encompasses users' reactions to *all* L&N dispatch computers which have been operating for eighteen months or longer. There are no skeletons in this closet.

In addition to these installations, L&N has five computer systems now going into service (with another seven analog and digital machines in production) as well as fifty modern, Area-Type Control Systems operating in major control centers.

When you make your decision regarding a computer, data processing or control system, look at the results. Then talk with our Field Engineers. They consistently deliver systems that measure up to their owners' expectations. Leeds & Northrup, 4972 Stenton Avenue, Philadelphia 44, Penna.

LEEDS & NORTHRUP
Pioneers in Precision

"WHEN SO MUCH DEPENDS ON SO LITTLE . . . IT PAYS TO RELY ON THE BEST"



Consulting Engineers: Ebasco Services Incorporated

4,000 PSI 1,000 °F (OR EVEN HIGHER WHEN YOU NEED IT!)

FEEDWATER HEATERS WITH YUBA'S EXCLUSIVE MULTILOK CLOSURE are capable in basic design of operating at the extreme pressures and temperatures required more and more by the power industry.

The Multilok Closure, a Yuba exclusive, is one of the important reasons why these units operate so efficiently and safely in the 4,000 PSI, 1,000° F range. And Yuba is prepared to produce units to handle even higher pressures and temperatures when needed. A pioneer in all-welded design, Yuba offers both all-welded and bolted construction – a complete and versatile line of feedwater heaters tor high and low ranges, for every type of job. When space is a critical factor, as many as three low pressure stages can be combined in a single shell for a highly compact unit.

Other Yuba products for steam power plants include condensers, evaporators, expansion joints, tanks, bridge and gantry cranes, structural steel erection, and scores of other items.

You'll want to discuss both design requirements and costs with Yuba heat transfer engineers during plant planning stages. The scope of Yuba designs will offer the best solution to your particular problem.

YUBA

specialists in power plant equipment

YUBA HEAT TRANSFER CORPORATION
Tulsa, Oklahoma
Plants in Tulsa and Honesdale, Pa.

YUBA CONSOLIDATED INDUSTRIES, INC.

Sales Offices in Principal Cities

Whether by blade or electric shaver, you know very well that it takes experience to get a perfect shave. And, that is no less true of fabricating and erecting critical piping. You'll stand to reap more satisfaction from beginning to end—if you delegate your high-temperature, high-pressure piping *directly* to experienced specialists. Next time ... ask us in!

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Philadelphia 46, Pa.

WESTPORT JOINT
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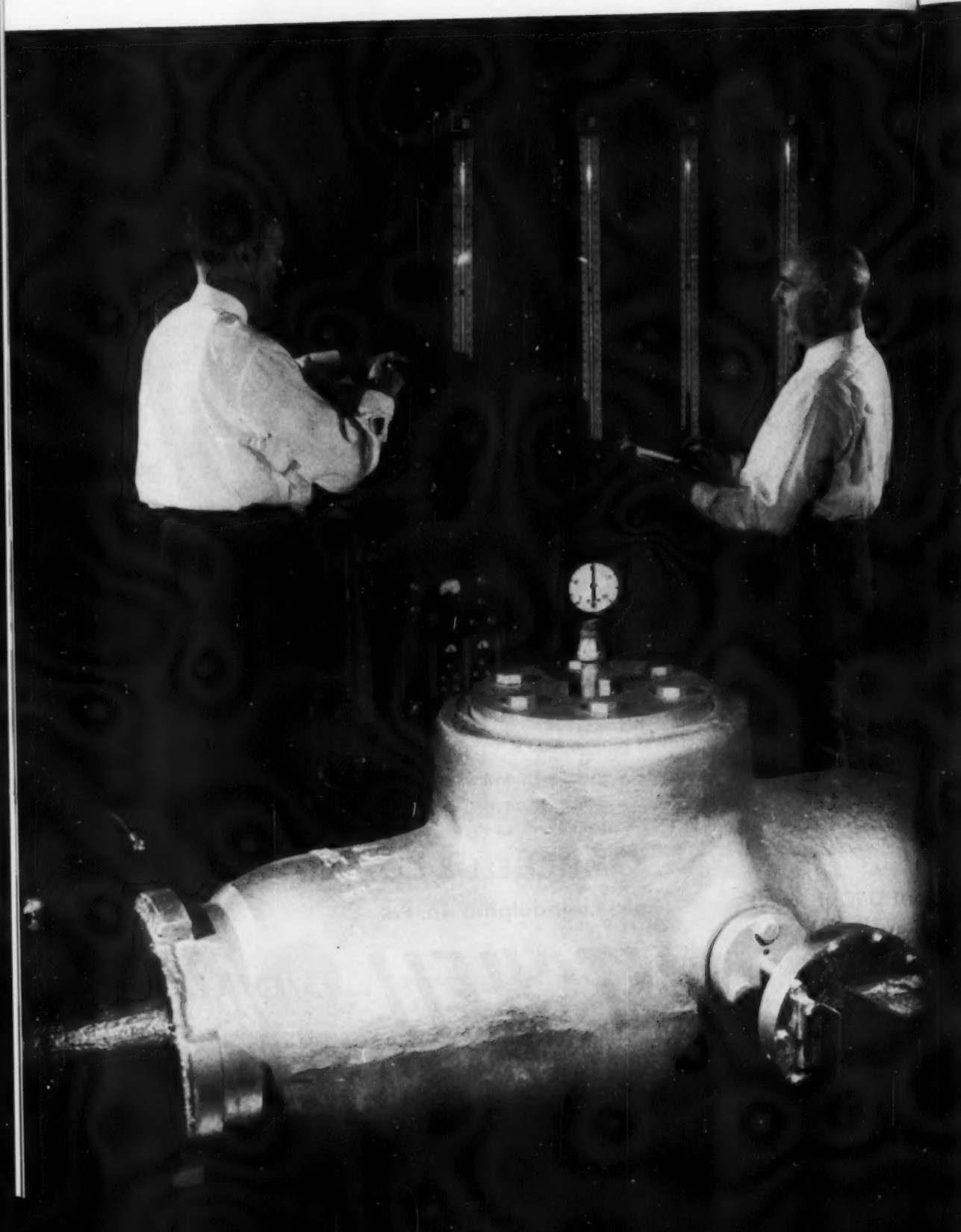
MITCHELL PIPING
SINCE 1899

PIPING FABRICATORS AND CONTRACTORS

The Story of Edward Research



and the Foolproof Check Valve

The design of the Edward tilting disk check valve started with a single objective: one-piece body construction. Edward designers were convinced that they could achieve this essential objective and, at the same time, assure ease of inspection and maintenance after the valve was welded in the line. Ideally, the valve also had to have these four important operating features: 1) Tight seating; 2) Non-stick operation; 3) Quiet, slamless closing; 4) Low pressure drop. Six years of research and testing gave them these desired features, and made possible this Edward success story.

ONE-PIECE CONSTRUCTION

Both manufacturing and engineering considerations indicated the wisdom of a design with the seat at a right angle to the pipe line. It was also essential that gravity close the disk, whether the pipe was in a horizontal or vertical position. Edward engineers solved this dual problem by welding a counterweight to the disk so that the force of gravity would pull the disk down tight on the seat whether the valve was installed horizontally or vertically. With this new disk idea, the valve seat could be formed of a single circular weld deposit of Stellite, and could be machined and finished through the end of the valve. The resultant one-piece body is virtually impervious to leakage or distortion.

TIGHT SEATING

Getting the disk to seat tightly was especially important because even a small amount of reverse flow was a hazard to pumps and compressors. Edward designers, after experimenting with several pivot positions, pivoted the disk half-way between its center and the upper seating surface. The tapered Stellite-faced disk closes on a tapered Stellite seat in the manner of a globe stop valve. When flow reverses, the larger lower portion of the disk swings downstream while the smaller upper portion swings upstream. Utilizing both gravity and the force of reverse flow, perfect alignment and tight seating are achieved.

SLAMLESS, NON-STICK OPERATION

The unique Edward water flow test loop with its 2,000,000 lb per hour capacity closely simulates actual service conditions. Edward researchers could observe the effects of vibration and water hammer at all stages of tilting disk development. Designing the valve to close quickly—before reverse velocity could build up—virtually eliminated slamming and vibration. Three features make this possible.

First, the disk is dome-shaped to avoid the hesitation of motion characteristic of flat disks. Second, disk travel is minimized by pivoting the disk in the flow stream. Finally, torsion springs enclosed in the pivot pins accelerate closing action from the full-open position. The valve closes efficiently and achieves maximum opening even at lowest flow rates.

LOW PRESSURE DROP

Minimum flow resistance was achieved through painstaking design of all surfaces in the flow line. Full port seat design plus streamlined disk and location of the counterweight out of the flow stream resulted in minimum pressure drop.

A FOOLPROOF VALVE

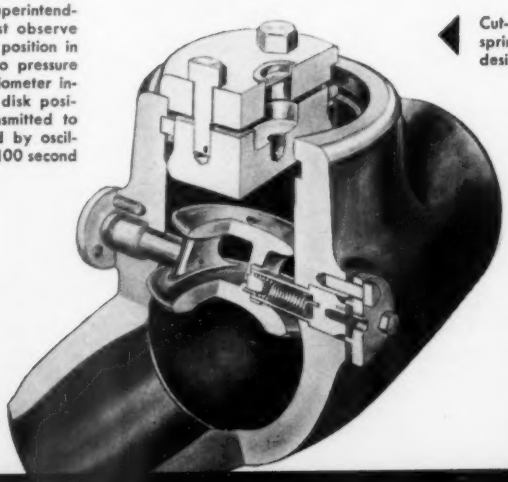
By tackling each problem separately—but always in relation to the entire design—Edward researchers came up with a tilting disk check valve that operated like no other check valve. It was dependable because it always functioned, effective because of its tight seating and low pressure drop, unique because it greatly minimized slamming, vibration, and water hammer.

This is the same tilting disk check valve, developed and patented by Edward Valves, that is so widely used in today's conventional, supercritical and nuclear power stations. Edward Catalog 14-Y gives full details.

Edward builds a complete line of forged and cast steel valves from ¼" to 24" for power, industrial, marine, and petroleum services. For more information, contact your Edward Representative, or write Edward Valves, Inc., 1206 West 145th Street, East Chicago, Indiana. Subsidiary of Rockwell Manufacturing Company. Represented in Canada by Lytle Engineering Specialties, Ltd., 438 St. Peter Street, Montreal. 6023

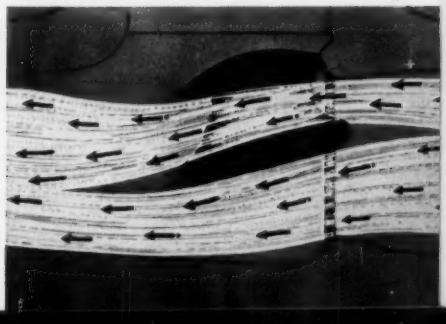
EDWARD STEEL VALVES
another fine product by
ROCKWELL

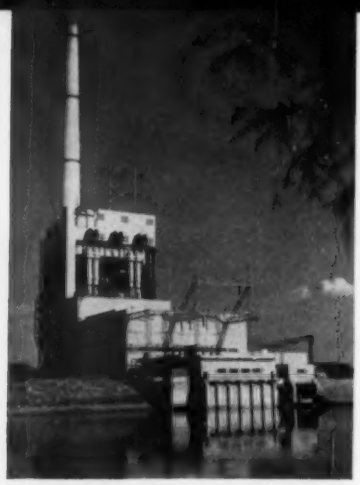
Director of Engineering and Research L. H. Carr and Plant Superintendent R. E. Rost observe test for disk position in relationship to pressure surge. Potentiometer indications of disk position are transmitted to and recorded by oscillograph in 1/100 second intervals.

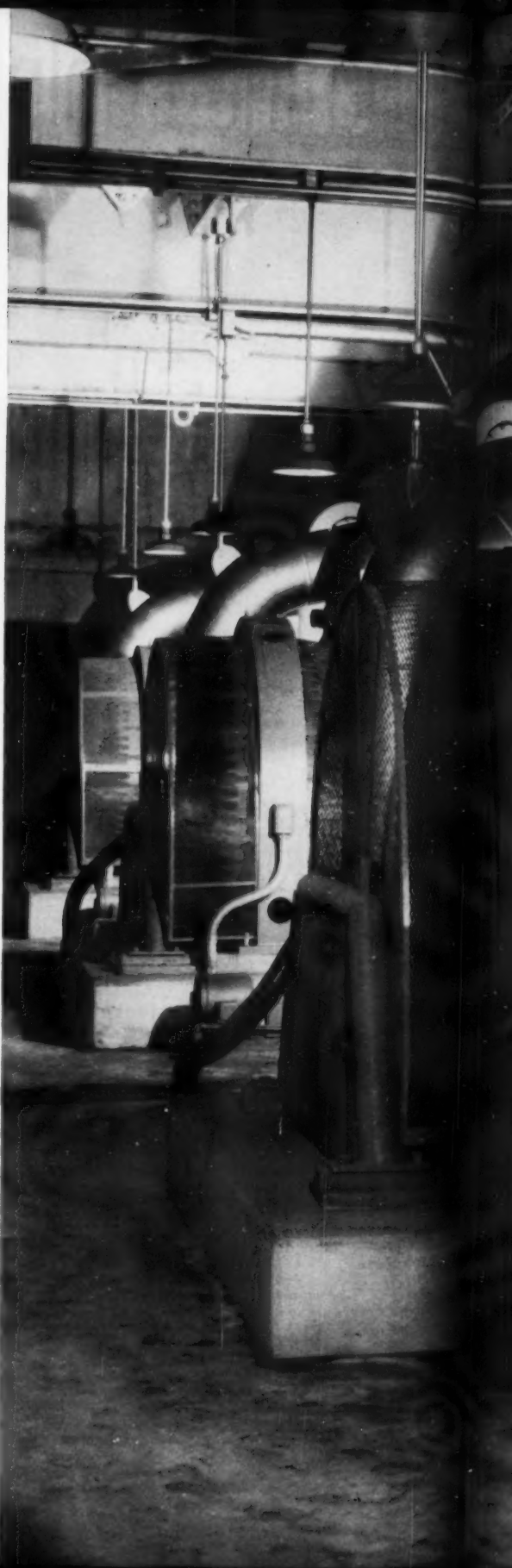


Cut-away view of Edward tilting disk check valve shows torsion springs enclosed in pivot pins, pressure seal cover and other design features.

In the open position the disk rests against a stop, thus minimizing disk flutter. Careful design of disk facilitates maximum opening, even at extremely low flow rates.







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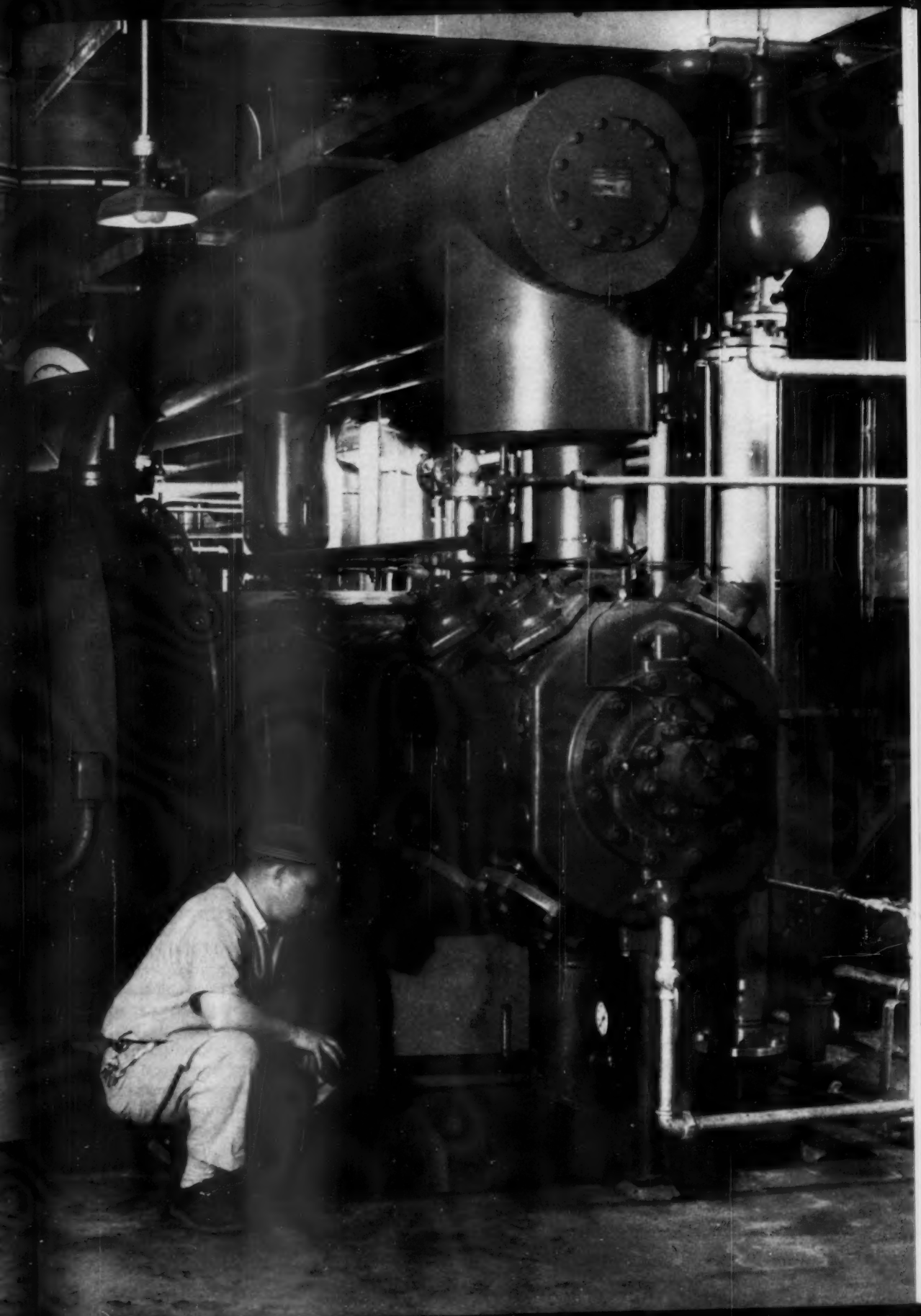
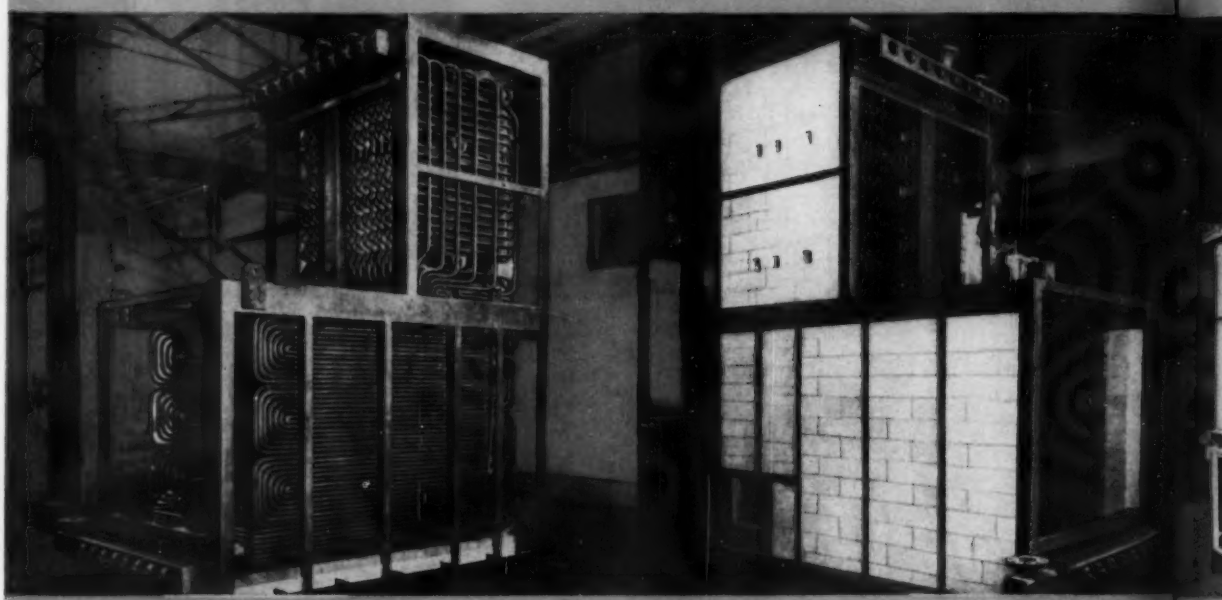


for space heating... or process heat... investigate the ECONOMY and EFFICIENCY of C-E HIGH TEMPERATURE



1 Shop assembly of 12-million Btu C-E High Temperature Water Boiler. Shows steel frame and pressure parts.

2 Same unit with refractory insulation added.

Because the C-E High Temperature Water Boiler makes more heat available than does a steam boiler operating at the same pressure . . . because it allows closer temperature control . . . does not require steam traps or elaborate feedwater treatment . . . has no blow down or condensate losses . . . it is finding ever-wider use in large space heating and industrial processing operations.

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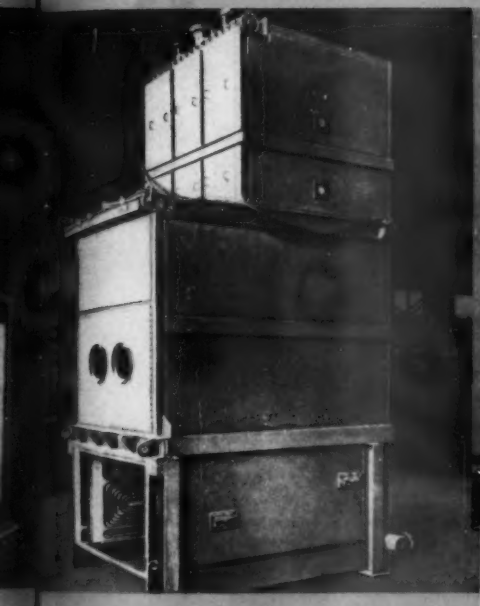
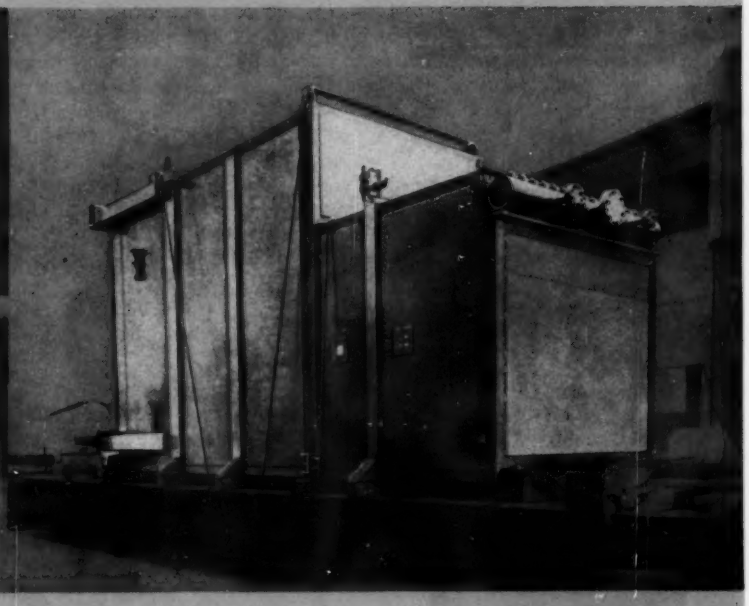


3 A 25-million Btu unit completed with welded casing, ready for shipment. Cables are attached to lifting lugs.



4 Compact, completely shop-assembled units from 20 to 35-million Btu are shipped this way.

This C-E practice greatly reduces erection costs.

So, if you are in the market for boilers, either for space heating or process requirements, it may prove to your advantage to investigate the use of high temperature water as your heat source. Because individual needs vary, both steam and hot water have their place. Our engineers will be pleased to discuss either method with you or your consultants — impartially and with no obligation.

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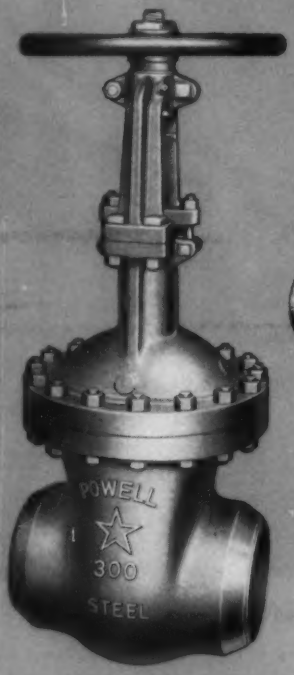
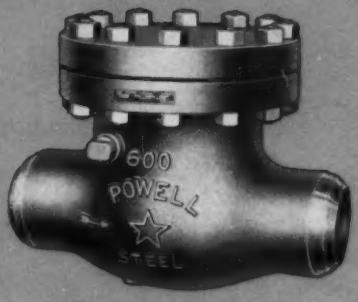
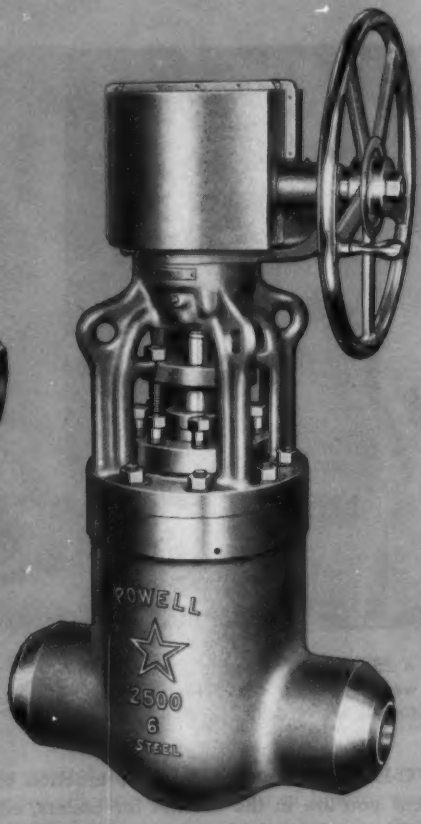


300-pound Steel Gate Valve—Fig. 3003 WE. Bolted flanged yoke-bonnet. Outside screw rising stem. Interchangeable solid or split wedges, renewable seats. Sizes, 1" through 30".



600-pound Steel Horizontal Swing Check Valve—Fig. 6061 WE. Bolted cap, renewable seat and disc. Has full flow area when valve is fully open.



2500-pound Steel Pressure Seal Gate Valve—Fig. 125003 WE. Enclosed bevel gears facilitate operation. Valves can also be supplied with spur gearing or motor operators for remote control.

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EDITORIAL

Progress and the Turnkey Contract

G. V. Williamson, recipient of the George Westinghouse Gold Medal at the recently concluded National Power Conference, and vice president, operations executive, of the Union Electric Co., set a number to thinking about the price of progress in any industry. The remarks which occasioned these thoughts were uttered by Mr. Williamson in salute to the participants—owners, manufacturers, specialists—who had given so much to the creation of Eddystone No. 1. Mr. Williamson was convinced that today many in operating companies were viewing power plants as commodities rather than engineering achievements. Hence price became the prime criterion in new plant expansion and he felt this to be a bad condition.

We heard and overheard a number of discussions occasioned by this conviction. Many felt the turnkey contract was the ultimate in the commodity approach and if universally accepted it would sound the death knell of progress. This comment brought back to mind the remarks of F. C. Heller, Babcock & Wilcox Co., before the ASME Annual Meeting this past winter. We quote in part: "Consider the effect of turnkey bidding on the various participants. From the manufacturer's viewpoint it appears he will have less opportunity to sell the fine points of his individual design. With all the equipment lumped together in one proposal, obviously the major emphasis will be on the bid price, with lowest cost per kilowatt generated being of primary importance. The cost of preparing bids will increase astronomically because, if several manufacturers of turbine equipment are required to bid to the buyer, then each boiler company will have to prepare bids for each turbine company and each auxiliary bid will be similarly multiplied. The buyer's operators will have to relinquish many prerogatives of design selection since, with the lowest bid price carrying the major weight in the award of a contract, manufacturers will be forced to furnish low cost equipment and lay it out in the least expensive manner.

"We may find that we have built up our costs due to lost motion and duplication of effort to a point where they are as high or higher than our former method of bidding. At the same time, both the buyer and the manufacturer may have lost their freedom of action."

Certainly under such an arrangement there would be no Eddystone. Yet this pressure for lower unit costs deserves a thorough review of present conventional approaches to power plant expansions. One obvious area for improvement is the practice of requiring manufacturers to submit many alternates on both an estimate and a firm price basis. Consulting engineers or the engineers on the buyers' staff can readily prepare feasibility studies based on approximate estimating figures that all manufacturers have which are up to date and accurate. Such studies should permit the selection of the most appropriate heat cycle for the proposed unit prior to the time formal bids are requested. There are undoubtedly other ways of obtaining economies without sacrificing individuality and engineering.

It will be a very sad situation indeed if the private interests who achieved the remarkable record that the power industry has made to date surrender progress for immediate dollars. Such a surrender will land the industry behind the New Frontiers.

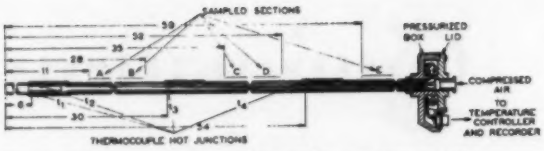


Fig. 1—High temperature deposition probe; part section, left.

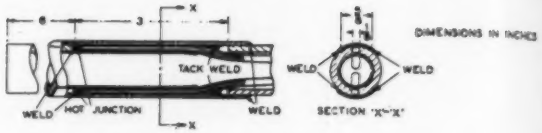


Fig. 2—Thermocouple mounting, above.

A simple and robust air-cooled probe providing a reproducible and easily manipulated target of known, variable temperature has been used to study the deposition of fuel-ash constituents from flue gas in boilers. It can realistically simulate heat-transfer elements at metal temperatures up to 900 C in boiler combustion chambers and superheaters; some typical results are quoted. All the equipment is available commercially.

By P. J. JACKSON Central Electricity Research Laboratories

A Probe for Studying the Deposition of Solid Material from Flue Gas at High Temperatures*

SERIOUS loss of availability of some power station boilers has been caused by the fouling and corrosion of superheater and combustion chamber wall tubes by constituents of the fuel ash. Such losses are symptomatic of the incompatability of the fuel, boiler, and operation, and variation of any or all of the factors involved is necessary for satisfactory operation of the plant.

The scientific investigation of these problems is difficult because the systems to be studied are complicated, and because it is impossible to reproduce in the laboratory the conditions in large boilers.

Past work has shown that the formation of troublesome fireside deposits depends on many factors, including fuel and ash composition, boiler and burner design, temperatures of flame, flue gas and tube surfaces, flue-gas velocity, soot-blowing practice and, not least, the degree of fouling of the boiler. The temperature gradient on the fireside of heat-exchange surfaces has an important influence on the physical and chemical differentiation of the ash constituents transported in the adjacent flue gas. However, the nature of the relationships between these factors and the fouling and corrosion experienced is at present very imperfectly known. This aspect is the subject of current research in several countries, not only to solve existing operational problems, but also to help to design and to predict the performance of future plant. To predict performance requires research into the behaviour of fuel ash under a wide variety of conditions, involving both work on the fundamental processes and observations of the behaviour of operating boilers.

By examining the deposits found in a boiler at the end of an operating campaign many useful data have been collected, but such data relate only to the fouling or corrosion produced by a specific, but usually ill-defined, set of circumstances, and provide relatively little information on the chemical and physical processes occurring while the boiler is in service. Results are obtained only after periods of several months, with risk of extensive damage to the plant and serious loss of availability. It could be very difficult, expensive and even dangerous to try to produce future combustion and heat-exchange conditions in existing boilers. For the purposes of research and development, however, such simulation must be attempted, and for this, equipment independent of the requirements for steam generation is required. The use of such experimental equipment confers the additional advantage of freedom to change independently most of the controlling variables.

Industrial research necessarily involves the interpretation of the results of "detached" laboratory work in terms of the behaviour of full-scale plant, and establish-

* Published in the July, 1961, issue of the Journal of the Institute of Fuel, London, England and printed by permission.

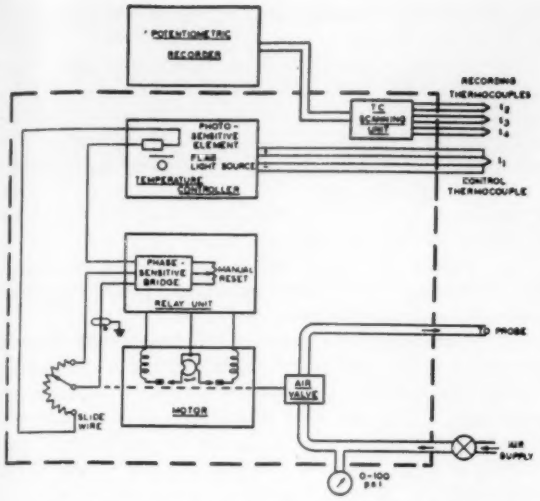


Fig. 3—Diagram of temperature controller and recorder connections

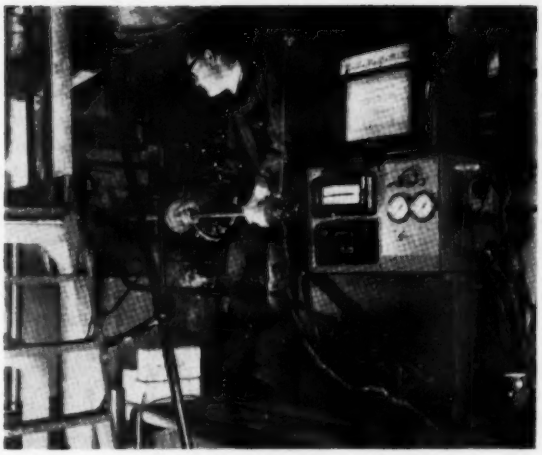


Fig. 4—Insertion of probe into superheater

ment of this connection between the two usually separate spheres of interest is often the most difficult part of the work. The authors, recognizing the need for a link between their laboratory work and operational trials of boiler fireside fouling in the C.E.G.B., (1)[1] have used probes of the type described here in associated "field" investigations (2, 3). The principle of this technique is the realistic simulation of boiler heating surfaces by the exposure of a retractable cooled probe to flue gas in an operating boiler, and the examination of the material deposited on it.

Such a procedure ensures the imposition on the test element of authentic, variable conditions, including the vital fireside temperature gradient, and permits the study of intermediate states of the deposits. It thus makes possible an investigation of some of the dynamic processes contributing to the formation of deposits while they are occurring *in situ*, a more revealing method than that of examining only the end products.

It was apparent to the authors that the very complex process of deposit formation could not be completely simulated by using this short-term technique. This was intended to provide information concerning the relative rates of mass transfer of fuel-ash constituents between flue gas and the cooler tube surface, to determine the composition of the material *being deposited* and to investigate as far as possible the chemical reactions of its constituents.

High-Temperature Deposition Probe

In designing a probe for the systematic study of deposition in superheaters and combustion chambers, the following should be observed:

(*a*) The probe must have a reasonably long life under the arduous operating conditions; therefore, it must be of simple and robust construction but, for ease of handling, light in weight. For convenience and practicability the services required should be the minimum.

(*b*) The temperature of the target must be easily controlled over a wide range. Simultaneous investigations at several temperatures would be desirable.

(*c*) The temperature of the target must be constant during each exposure, it must be accurately known and preferably recorded continuously.

(*d*) Contamination of the deposits by the target material should be minimized. The target surface must be closely reproducible from test to test.

(*e*) The target area should be large enough to permit the collection of adequate quantities of deposit, and ideally there should be a freedom of choice of samples with respect to both position on the probe and target temperature.

(*f*) The methods of analysing the deposits must be sufficiently sensitive to yield results of adequate precision with the small samples obtained from short exposures.

Cooled probes have been used to assess the rate of fouling of superheaters (4) and for investigations of the fireside wastage of superheater materials (4, 5). Somewhat similar probes have been employed to investigate the potential corrosion of air-heater materials in oil-fired boilers (6–9), and another, developed from the high-temperature probe described here, has been used for measuring the rate of deposition of acid in boilers at temperatures near to, and below the acid dewpoint (10).

At the inception of this phase of the authors' work no probe or technique described in the published literature completely satisfied these requirements. The only probe which had been used for studying deposit formation in high-temperature regions of boilers (4) was suitable only for long-term testing, since its complicated construction and operation did not permit a rapid turn-round between exposures; the use of detachable target plates was considered unsatisfactory. The equipment described here was therefore developed, repeated tests being made under a variety of exposure conditions in several power stations. An early form of this probe has been described briefly by M. E. Peplow (11), and a more detailed description appears in a Boiler Availability Committee (12) Bulletin.

Figs. 1 and 2 show the general arrangement of the

[1] Numbers in parentheses refer to similarly numbered entries in the List of References at the conclusion of the article.

probe and the method of mounting the thermocouples. The probe is made of austenitic steel (18 per cent Cr, 10 per cent Ni, 3 per cent Mo type) tubing, 1 in. O.D., $^3/_4$ in. I.D., and is basically similar to that used for measuring acid deposition rate (10). The principal difference is the greater length which is necessary to avoid the steep gradient in flue-gas temperature near the boiler walls, and to allow for the thickness of those walls, while still providing a test section several feet long to permit the simultaneous collection of samples on surfaces at temperatures in a wide range (300 F). Probes 13 ft long overall have been used successfully, but they were rather too long for convenient handling and an overall length of 11 ft is the optimum for most boilers.

It is essential that good thermal contact is made in the welds between the sheaths of the thermocouples and the tube wall as shown in Fig. 2; a brazing alloy of high-melting temperature may be used instead.

The accuracy of registration of the probe-metal temperature by the mounted thermocouples was checked by packing materials of known melting temperature in small cavities close to the hot junctions of the thermocouples, for several exposures of the probe in the superheater of a pulverized-fuel-fired boiler. Any discrepancy was not significantly greater than the variations of temperature measurement by the potentiometric recorder in the experimental condition, about ± 15 F at 1300 F. It is probable that any bias in temperature registration does not exceed ± 10 F.

The cooling air may be controlled manually or by an automatic system, shown diagrammatically in Fig. 3. Four chromel-alumel thermocouples are normally fitted to the probe, one of the duplicates at the hottest position being connected to the auto-controller. A safety device is included in this thermocouple circuit; if the control thermocouple fails, the cooling air control valve opens fully to prevent damage to the probe by overheating. All the control equipment is mounted in one case.

A fast-response cold junction-compensated potentiometric recorder, with a range of 500 F to 1500 F, is connected to the other three thermocouples through an automatic switch with a cycle period of two minutes.

Operation

"Shading" by upstream tubes in the boiler should, if possible, be avoided when choosing the site for exposing the probe. If a "shaded" site is unavoidable, the positions on the probe from which samples are collected must be judiciously chosen.

For satisfactory operation a continuous supply of dry compressed air is required, at 80 to 100 psig, via a pipeline of at least $^3/_4$ in. bore. If there is an appreciable amount of water in the compressed-air supply a suitable trap should be installed on the supply side of the controller.

At the sampling site there should be sufficient space and illumination for comfortable manipulation of the probe, and loose dust should be removed from the immediate surroundings to minimize the risk of contaminating the samples. The probe must be sealed in the access port to prevent "blanketing" of part of the probe surface with air drawn in by the boiler suction, and there must be adequate clearance for the easy removal of the probe and attached deposits. Immediately before insertion, the whole of that part of the probe exposed to the flue gas should be thoroughly washed, and scrubbed if necessary, to remove adhering deposits, using water of "distilled" purity. Thereafter, the probe surface should not be touched until the samples have been removed. Care should be taken to prevent contamination of the samples by stray dust outside the boiler or around the access port. With careful working, even in dusty atmospheres, errors in determinations of sodium, for instance, need be no more than 5 $\mu g\ cm^{-2}$ and are usually much less than this.

Fig. 4 shows the probe being inserted into the superheater chamber in a difficult situation; the temperature controller and recorder are on the right.

After insertion, the probe must reach the desired temperature as quickly as possible, but overshooting should be avoided; the optimum control settings are soon found. The duration of the exposure is measured from the time of insertion to the time of withdrawal, and will depend greatly on the conditions under which the tests are made. When the rate of deposition of ash is very high, it is advisable to carry out a few preliminary runs to determine a suitable exposure period. For example, when the probe was used in the middle of the combustion chamber of a p.f.-fired boiler the formation of slag on the probe was so rapid ($10^7 \mu g\ cm^{-2}h^{-1}$) as to limit the test period to 5 min. For investigating the chemical reactions of deposited material in superheater passes, exposure periods have been varied from 15 min to 24 hr in a series of tests.

The method of collecting samples from the probe depends on the quantity and on the nature of the material accumulated. Washing of sections of the probe using "deionized" water is the most convenient and effective way to collect the small quantities of fine material usually deposited in superheaters. A sample of the water used at the sampling site should be retained for determination of analysis "blank" values. A small stiff brush—a toothbrush is ideal—can be used to detach any insoluble material which adheres to the probe. A convenient technique for washing the probe has been described; (10) a suitable disposition of sampling sections for washings is indicated in Fig. 1.

Thick deposits are sampled by laying the probe on metal trays immediately after withdrawal from the access port. Any bonded, sintered or fused material is separated from the loose dust adjacent to the probe, as shown in Fig. 5. The finer material adhering to the probe may be sampled by washing or by brushing it into a shallow tray. The samples of "slag," dust and washings should be packed and examined separately, as each type of material has peculiar properties characteristic of the conditions of deposition being investigated. For each run, the mean recorded temperatures of the three thermocouples (t_2, t_3 and t_4) are plotted on a graph, as in Fig. 6, from which the mean temperature of each sampled section can be read.

It is always advisable to sample the fuel corresponding to each exposure of the probe; for long exposures several samples may be required to ensure correct representation of average conditions. Pulverized fuel is most conveniently sampled from the pipes leading directly to the burner or burners appropriate to the position of the probe; care must be taken to avoid large sampling errors due to segregation of fuel in the primary-air stream. In timing the fuel sample, due allowance must be made for

Fig. 5—Sampling: deposits of fused ash

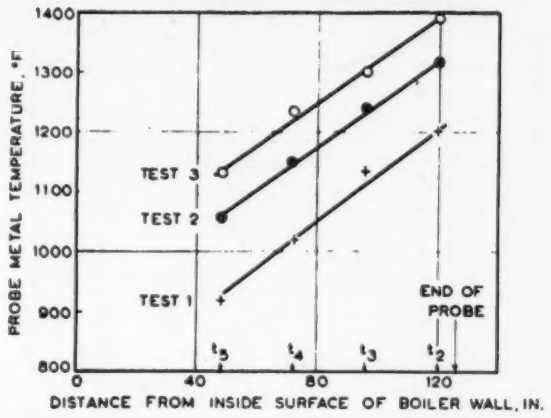


Fig. 6—Temperature gradient of the test section of the probe (flue-gas temperature about 2000 F)

the delay between the sampling point and passage of corresponding combustion products past the deposition probe.

A detailed description of the methods of analysis for the various types of samples which may be collected with the probe is not appropriate to this paper. However, the general principles given below may serve as a guide to the method of examining such material.

The rate of deposition of the total solid material on the different parts of the probe can be determined by weighing the samples; this procedure usually is suitable only for "slag" or sintered ash, and can yield useful comparative information concerning potential rates of fouling.

Samples of dust, sintered or fused deposits should be examined using a stereoscopic microscope of relatively low power (× 10 to × 200). When there is a sufficient quantity of such a sample, say at least 0.05 g, it can be analysed chemically.

Chemical analysis of the water-soluble portion of the finer material and of probe washings will be most informative. This fraction contains most of the reactive constituents responsible for fouling and corrosion in high-temperature boiler passes. An adequate assessment of the nature of the deposit can be made by determining the soluble sodium, potassium, calcium, silicon, sulphate and chloride and, in oil-fired boilers, vanadium. The molar ratios of some of these constituents and the abundance of each in the total deposit should be calculated. A comprehensive scheme of rapid methods of semi-micro analysis for the fireside deposits from probes and boiler surfaces has been developed at C.E.R.L.; analysis with separate determinations of the principal constituents in the water-soluble and insoluble fractions requires about 0.05 g of sample. In deposits from coal-fired boilers, the following radicals are usually determined: silicate, aluminum, ferrous and ferric iron, calcium, magnesium, potassium, sodium, sulphate and chloride; in deposits from oil-fired plant: ferrous and ferric iron, vanadium, nickel, chromium, calcium, magnesium, sodium, sulphate and chloride. When appropriate, zinc, manganese and orthophosphate can also be determined. This scheme of analysis is specially designed for routine application and requires the use of a simple flame photometer and an optical absorptiometer of the monochromator or filter type. All these water-soluble and insoluble constituents of ten samples can be determined in five days.

It is not always necessary to determine all the constituents enumerated above. Current research using the probe has as one objective the search for one or two parameters indicative of fouling and/or corrosion.

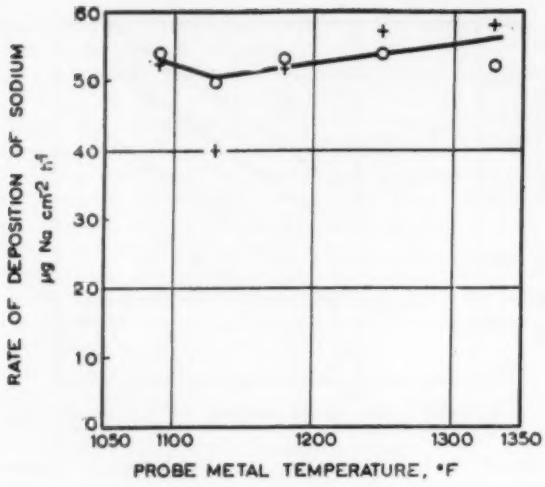
Experience

Probes of this type have been used in the combustion chambers of p.f.-fired boilers, (3) and in the superheater passes of dry-bottom p.f., (2) cyclone- and oil-fired boilers. Because the equipment and technique were designed specifically for use in power stations, it was easy to make accurate measurements rapidly and with few precautions; the turn-round time between runs was usually about 5 to 10 min, depending upon the complication of the sample collection. In the combustion chamber the range of probe metal temperatures could be controlled from about 1000 F to 1800 F. The lowest temperature obtainable on the air-cooled probe depends on the rate of heat transfer by convection from the flue gas and by radiation from the flame, and inversely on the pressure of the compressed-air supply.

The temperature of the test sections of the probe was easily and accurately controlled in the range 300 F to 1500 F in the superheater region, with flue-gas temperatures between 1000 F and 2100 F. A 13-ft probe with four thermocouples at 2-ft intervals was used to investigate the temperature distribution along the probe. The results, in Fig. 6, show that for the test section, well away from the boiler wall, the temperature gradient was linear within the order of experimental error (± 20 F).

When probes were used in the combustion chamber of a modern boiler near the p.f. burners, where the flue-gas temperature was in the range 2500 F to 2800 F, it was not possible to reduce the probe metal temperature to that of the furnace-wall tubes, 500 F to 700 F, by using air alone as coolant. Shorter probes, 6 ft long overall were made, the thermocouples being placed at smaller intervals, and a small proportion of water was sprayed into the cooling air through a fine nozzle at the inlet to each probe. This enabled the temperatures to be reduced, but precise temperature control was difficult, due to variations in the supply pressures of water and air. Satisfactory cooling is expected to be provided by finer methods of controlling the flow of the coolants.

When reasonable care was taken in collecting the samples, satisfactorily repeatable results were obtained. As an example, Fig. 7 shows the results of duplicate runs for determining the rate of deposition of sodium on the probe exposed on the furnace side of the secondary



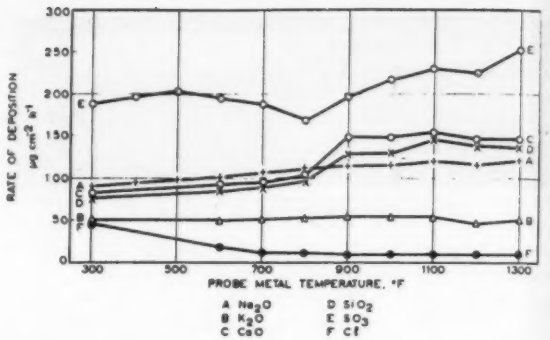


Fig. 8—Rates of deposition of water-soluble sodium, potassium and calcium oxides, silica, sulphur trioxide and chloride

←

Fig. 7—Rate of deposition of sodium (two one-hour tests)

superheater in an oil-fired boiler. Sodium sulphate was the principal constituent of the deposit; the proportion of vanadium was much less than that of sodium, and nearly all of it was insoluble at the lower temperatures.

In some coal-fired boilers greater variations in the results— ± 20 per cent—have been due to rapid changes in the composition of the fuel burnt during the series of tests. Satisfactory compensation for such variations can be made by considering the changes in ash content and composition determined from the samples of fuel taken simultaneously with the probe exposures. Changes in the boiler load, by altering flame temperatures and flue gas velocities, may also have pronounced effects on the rate of deposition and on the composition of the material deposited on the probe at any one position of exposure.

Fig. 8 shows the results of tests on a "dry-bottom" p.f.-fired boiler burning a coal of high chlorine content (2) (chlorine 1.0 per cent, sulphur 0.9 per cent, ash 18.0 per cent). The probe was inserted between the primary and secondary superheaters. Most of the sodium, potassium and calcium were combined as sulphates; much less chloride was found at temperatures above about 700 F. The appreciable proportion of soluble silicate resulted from the attack by alkali-metal and calcium compounds on the insoluble silicates in the fuel. The layer formed by this process on the surface of the ash particles in the combustion chamber has a relatively low softening temperature; it may, therefore, act as the bonding agent in the formation of sintered deposits, at temperatures well below the softening point of the bulk of the ash, on surfaces of which the temperature is sufficiently high. The increase in the proportion of soluble silicate found on the probe at temperatures above about 900 F is considered to indicate a strong fouling tendency; (1) the boiler trial during which these tests were made ended after about 350 hr, due to blocking of the secondary superheater by sintered ash.

The foregoing instance illustrates briefly an application of this deposition probe to the investigation of boiler fireside fouling and corrosion. Detailed studies have been made using the technique described here under a variety of conditions and have included comparisons of the material deposited on the probe and on the boiler tubes with the inorganic matter in the fuels and the "fly" ash in the flue gas. Presentation of the results is beyond the scope of this paper, and it is proposed to describe the results of these investigations separately.

Conclusions

Experience in using this high-temperature deposition probe in a wide variety of power station boilers has shown it to give results which realistically represent the behaviour of ash constituents during and after combustion of the fuel. When combined with special methods of examining the deposited material, the technique provides a simple and effective method of investigating the fundamental chemical reactions proceeding in otherwise inaccessible regions of operating boiler plant. The use of this probe establishes a valuable link with research in the laboratory. It has shown directly and rapidly the conditions in full-scale plant, with very little expenditure on labour, materials or capital equipment.

In application to problems of boiler fouling and corrosion it is most versatile, having been equally suitable for collecting fused slag formed from a p.f. flame and for assessing precisely the deposition of sodium from flue gas in an oil-fired boiler, containing about 2 mg. m^{-3} of sodium. The surface of the probe on which deposits are collected is at a known temperature, is easily reproducible from test to test, and does not significantly contaminate the sample. Simultaneous measurements are made at a usefully wide range of temperatures. The method of assessing deposition rates appears to be sufficiently sensitive to detect significant changes in the behaviour of the ash constituents involved in boiler fireside fouling.

The probe is robust, is simple to operate and requires few services for its operation (compressed air and mains a.c.). A reliable auto-controller is available for long exposures and the temperature recorder is a standard range instrument. All the equipment is available commercially. The rapid methods of chemical analysis developed for use in this work require no special or expensive apparatus.

Acknowledgments

Grateful acknowledgment is made of the facilities and assistance given by many colleagues in the power

stations of the Central Electricity Generating Board which enabled this equipment to be developed and tested. C. Heritage of the Instruments Section C.E.R.L. assisted in designing the temperature controller.

This paper is published by permission of Dr. J. S. Forrest, Director of the Central Electricity Research Laboratories, Leatherhead.

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Necessity of Blowing Out New Piping*

By C. N. MACDONALD, R. B. BLACK, and S. MAKAR

REALIZATION for need of a better pipe cleaning method came in November 1955 with the completion of the Delray Industrial high pressure steam line.[1] The Delray line consists of 1700 ft. of 12-in. pipe above ground and 6500 ft of 12-in. and 10-in. main installed underground. This line was designed to operate at 400 psig. During the installation, the pipe was not subjected to any special cleaning method, other than striking it several blows with a small sledge hammer, while suspended in mid-air. This method of cleaning low pressure piping has been considered reasonably effective in removing a greater portion of mill scale and foreign material, with the balance of the sediment being removed through the steam traps during the warm-up period.

During the warm-up of the Delray line and the first few months of operation, it became apparent that a more thorough cleaning method was required. Steam traps repeatedly became plugged with sediment and rupture discs in the safety head were punctured, indicating that the flow of steam was cleaning the pipe surface and moving foreign objects. The mill scale and foreign objects moving with the steam at high velocities is very abrasive. The stainless steel stem of a customer's pressure reducing valve, at the extreme end of the line, was badly eroded by this abrasive action.

There are primarily two problems in blowing out steam lines. First, there must be sufficient steam capacity to propel any sediment in the pipe to the "blow-out" point. Second, the location of the blow-out" point must be so chosen that the general public and property in the vicinity can be protected. The Delray line would have been ideal for such a "blow-out" method because of its capacity and its industrial location.

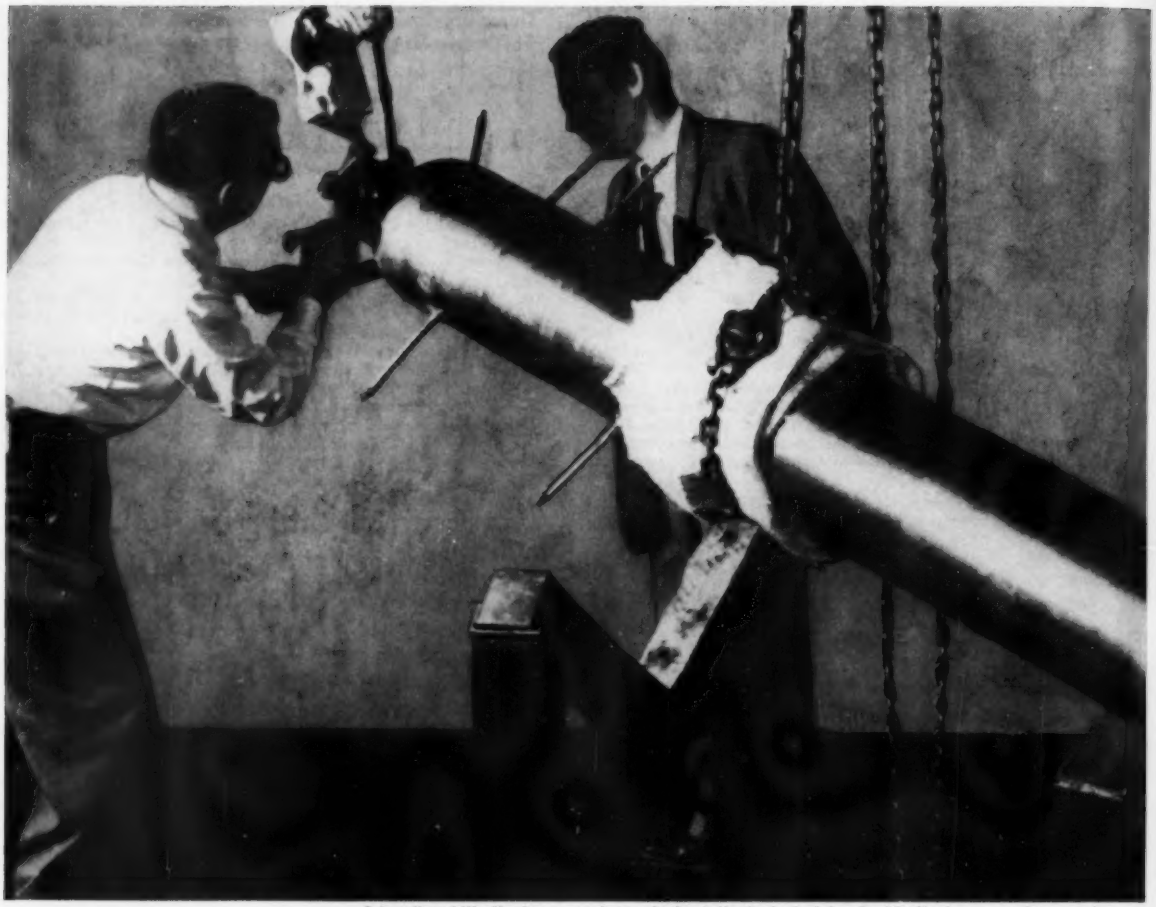
The line selected to try this "Blow-out" pipe cleaning method was a new 20 in. steam feeder, installed in 1956, which was designed to operate at 150 psig, starting from our Beacon Heating Plant and terminating in an existing manhole at Brush and Willis, a distance of 7000 ft in length. Prior to putting this line in service, a blow-out procedure was determined between the Underground Lines and Central Heating Departments.

The line was installed complete to the extreme end and blanked off in the terminal manhole. Both Departments were of the opinion that heating and cooling of the pipe would loosen the mill scale and rust within the pipe by expansion and contraction. To accomplish this, the line was warmed up gradually to a pressure of 75 psig, regulated by a valve in the plant, and maintained at this pressure for a three-day period. The plant valve was then closed allowing the pressure to dissipate without any blow-out. The steam traps were then taken apart for inspection and cleaning. Approximately 31 lb of sediment was removed from the steam traps. The line was again warmed up gradually to a pressure of 145 psig and maintained at this pressure for another three days. The plant valve was again closed allowing the pressure to dissipate without any blow-out. The steam traps were again taken apart for inspection and cleaning. This time, however, approximately $^1/_2$ lb of sediment was removed from the steam traps.

Inside the manhole, a large sheet of plywood was installed about 18-in. from the end of the pipe to shield the opposite manhole wall. Manhole covers over the chimney openings acted as baffles.

The blank was then removed from the end of the main, and the valve at the Plant was opened. The pressure was raised from 0 to 38 psi in a period of 15 min., resulting in an approximate flow of 150,000 lb per hour at the Plant. The plant valve was then closed. Approximately 73 lb of sediment was collected from the manhole floor. This was a great deal more than anyone had expected, and represents an untold savings in time and effort over what there would have been had our servicemen been required to remove the same amount of sediment from various customer's equipment.

* Presented at the 52nd Annual Meeting, National District Heating Assn. Portsmouth, N. H., June, 1961.
[1] "New Industrial Steam Line in Detroit" by Carl W. Signor and Glen D. Winans; Proceedings, National District Heating Association, 1956, Page 40.



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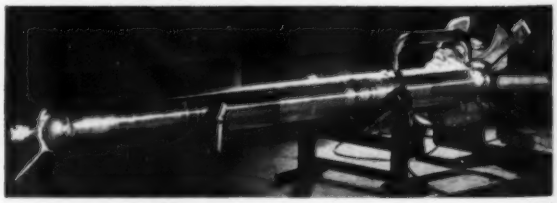

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Removal of Slag Deposits from Screen Type Superheaters by Vibration Methods*

IN RECENT years screen type superheaters located at the furnace chamber exit are finding increasingly wider application in today's large pulverized coal burning units. This is due, not only to the use of higher steam temperatures, but also to the use of single units of greater capacities and designed for higher efficiencies.

Up to recent times there has been little or no experience in cleaning screen type superheaters of external deposits. These deposits have a two-fold effect, that of clogging the passage and reducing the heat absorption. In 1954, at the All-Union Thermal Engineering Institute Laboratory, experiments were conducted on cleaning slag covered tubes by vibration methods (N. V. Kyznetsov). This work established the experience of using vibration for this purpose and it was shown that the best cleaning was obtained by the use of a direct vibrator. (*Editor's Note: For further information on this subject see "Vibration Cleaning Boiler Heating Surfaces" by V. I. Chastoukhin and E. L. Zarechansky,* COMBUSTION, *Nov. 1959.*)

Available Soviet experience on cleaning economizers and convection superheaters (Shakhtinskaya State Regional Electric Power Plant, Shterovskaya State Regional Electric Power Plant, Bezymyanskaya Heat and Electric Power Plant) indicates the soundness of this thinking. Information recently published concerning foreign experience further confirms the justification of the method described in this article.

Boiler and Superheater Characteristics and the Properties of Screen Slag Formation

The evaporating capacity of the boiler of which the 1954 Laboratory tests were conducted was 160 tons per hr at a pressure of 120 kg/cm² and a total steam temperature of 500 C (Fig. 1). The furnace consists of a single chamber designed for slag tap removal. Pulverized coal of the type ASH having a grinding fineness of $R_{88} = 7$ to 9 per cent is burned in banks of three turbulent burners mounted on each side wall of furnace chamber.

The screen superheater in the general scheme is in the primary steam path and consists of 32 elements having a diameter of 44.5 × 4.5 mm. The steam after passing through the steam scrubber enters four screens constituting the first superheater pass; then after changing over moves through four screens of the second pass.

Slagging of the screen superheater was observed during the operation of the boiler. The furnace gases increased in temperature and at a position in front of the screen the average temperature was 1300 C. A significant portion of the screen superheater was covered with slag crust in the course of 5 to 6 days operation. The slag thickness varied. In the lower section it was about 30–40 mm with approximately 10 mm at the upper section. At the extreme lower ends of the screen the slag increased up to about 200 mm. In contrast to the slag crust on the tubes above, which was intensely hard and had a brilliant black color, this heavier build-up was porous, of little strength, dark but not brilliant in color.

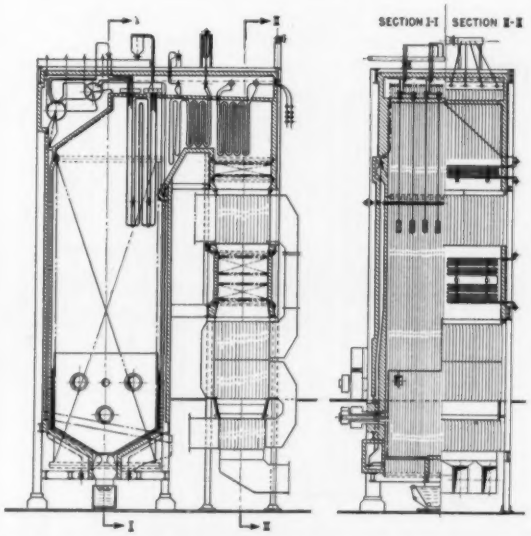

Fig. 1—General view of the 160 ton per hr boiler used for laboratory tests of a vibrating slag cleaner

* Published in the Electricheskiye, Stansii, No. 3, 1960, pp. 2–7, and translated by V. A. Ferencko, Combustion Engineering, Inc.

TABLE I—VIBRATION TEST RESULTS ON LABORATORY UNIT

Indicators	28/ XI	1/ XI	3/ XII	4/ XII	7/ XII	8/ XII	9/ XII	10/ XII	11/ XII	18/ XII	19/ XII	20/ XII	21/ XII	22/ XII	23/ XII	24/ XII
Steam evaporation, tons per hr.	152	152	151	143	144	159	160	155	153	147	150	147	135	161	161	150
Duration of blr. oper., hrs	41	113	161	185	257	281	305	329	353	521	545	569	593	617	641	665
Coeff. of excess air at furnace exit	...	1.21	1.24	1.29	1.20	1.23	1.21	1.17	1.21	1.17	1.15	1.2	1.24	1.21	1.16	1.18
Relative Increase of steam heat content																
In No. 1 screen	37.6	38.8	41.3	38.7	39.7	36.7	...	42	46.8	43	47.8	49.8	51	53	43.9	46.4
In No. 3 screen	37.2	31.4	37.2	34.2	37.8	35.6	...	39.2	42	37.1	39.8	38.8	35.6	36	33.9	37.6
In No. 5 screen	39	34.1	35.8	36.5	31.1	39	50	42.2	42	39.5	43.2	41.2	37	42.9	37.1	37.4
In No. 7 screen	38	36.2	36.5	36.4	36.7	35.6	47.8	42.4	39.4	48.7	49.6	51.1	48	50.8	47	47.6
Total steam heat content increase in the screen superheater.[1] Kg cal/k (See Fig. 4 for values)	79.8 / 76.2	73.6 / 69.7	79.0 / 75.2	74.8 / 71.5	76.6 / 73.0	78.4 / 73.6	94.4 / 92.4	83.4 / 82.9	92.4 / 85.9	91 / 85.6	96.6 / 89.5	97.4 / 89.4	93.6 / 86.4	95 / 90.8	85.2 / 80	90.4 / 84.1
Combustible content in fuel carryoff, per cent	. .	14	9	8.5	13	9.5	8.5	13	9	10	11	8	11	10	10	8
Grinding fineness of the pulverized coal	...	10	11.8	8.8	8.3	9.6	9.8	9.5	10.4	9.6	9	8	5.7	8.4	8.2	9.5
Gas temperature at the furnace exit, deg C	...	...	...	...	...	...	...	...	...	135	1346	1334	1288	1290	1371	1378

[1] In the numerator—visible heat contact increase. In the denominator—relative heat control increase.

Vibration Device

The actual cleaning operation results from oscillations transmitted to the freely suspended tube screens by means of vibrators which are tightly connected with the tubes.[2] The motion so induced permits the tubes to clean themselves. The principal difference as compared to foreign methods[1] is that the vibrations are transmitted perpendicular to the screen surface. Four vibrators, two per side, are mounted on the superheater structure. The vibrators are rigidly fastened to the screen to minimize oscillation fadeout.

Expansion due to temperature changes taking place in the welded tubes were provided for by their U-shaped configuration giving flexibility in their length and in the bends as they entered the headers. At the weld level the tubes are tightly fastened together for alignment. Cooling rods perpendicular to the screen surface connect to the four screen tubes and to the adjoining screen by the use of ribs made from 15-XM steel. The cooling rod is a tube 76 × 6 mm in diameter, inside of which is inserted a tube 57 × 3.5 mm in diameter. This provides a radial clearance for the passage of cooling water. Both tubes are constructed of carbon steel. The rods exit through the furnace casing by means of an inserted oval cast iron shell provided with proper clearance for both vertical and horizontal expansion bearing in mind the screens themselves can move 35–40 mm under furnace temperature changes. Flaked asbestos packing and sealing sleeves of asbestos web are used to minimize leakage. For relief from extra weight due to the vibrators, the rod ends are loosely suspended from the boiler frame through the application of steel cables passed over pulleys and counterweighed.

[1] D. Hauschild, E. Lorentz, Energietechnik, 1958.
[2] This design was developed under the supervision of Engineer E. M. Livshitz.

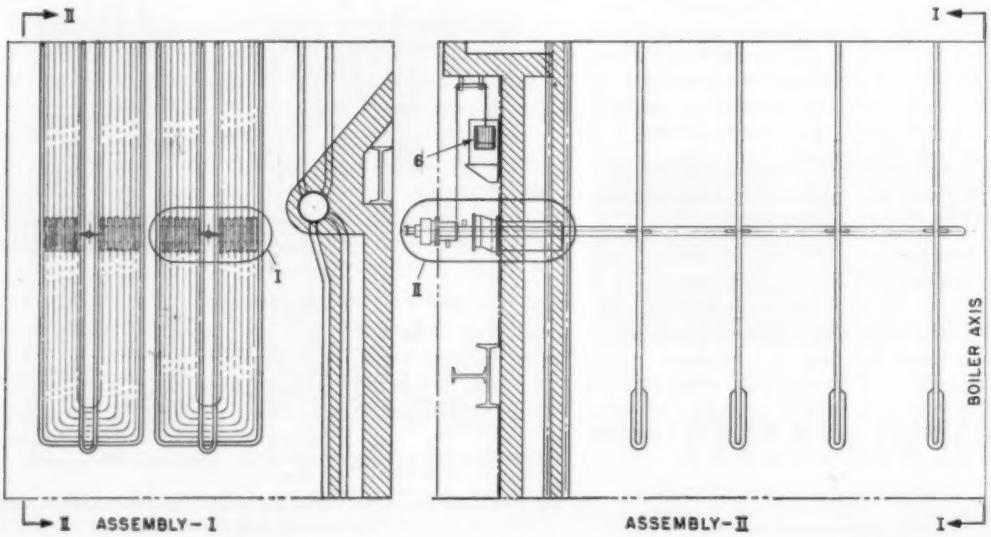

Fig. 2 is explained in Fig. 2a facing page

Four eccentric type C-433-A electric vibrators with motors having a capacity of 0.6 kw, a voltage of 220/380 and a speed of 2800 rpm were provided. The vibrator is so designed that the eccentric device starts operating only after reaching rated speed. This insures that while switching on or off the vibrator system does not run through resonance frequency.

Feedwater (P = 25 ata, C = 120 C) is used to cool the rods and is discharged to an expansion tank at a temperature of (155 to 160 C). The water consumption through each rod is approximatey 1.5 tons per hr.

A switch on the boiler panel puts into operation two vibrators on each side of the unit and time relays and indicating lamps are included in the control circuit.

Testing the Vibrator Installation and the Results of the Tests

Vibration amplitudes at various points of the superheater screen, Fig. 3, were measured on the cold boiler by means of a VR-1 vibrograph. Measurements verified a monotonous decrease in amplitude along the length of the bar. This is probably the result of absorption or is due to the inertia of the screens which are attached to the rods or to the elastic deformation of an individual rod itself. This phase of the problem would require special study.

On the left side, nearest to the vibrator, the amplitude measured 1.1 mm decreasing to 0.4 mm at the extreme end of the rod. On the right side the corresponding measurements were 0.8 and 0.2 mm. At other locations the measurements showed intermediate amplitudes. There seems to be no practical amplitude change across the screen width.

Optimum operation of the vibrator device was obtained by taking measurements along the screen end by visual observation during the adjustment tests. As anticipated, clogging of the screen took place from the first day of operation and progressed extremely fast requiring the use of the vibrators for a period of nine seconds every 2 hr.

Seven main tests were conducted during the period Dec. 18–24, 1958, for a total of more than 500 hr of boiler operation. Regular vibrational cleaning of the screen took place during this time.

Some of the adjustments and the main test results are included in Table I. When reviewing the data the heat contents of the steam at the inlet and outlet of the second superheater path are calculated as the weighted mean for the four flow paths.

The total increase in heat contents of the screen superheater ($\Delta_{i_{sss}}$) is calculated as a twofold increase of the heat contents of the second pass screens. The value Δ_i is established by direct measurements. For all tests the relative increase in heat contents in the screen superheater is based on the following:

$$\Delta_{i_{sss}} = \Delta_{i_{sss}} (1 - \mu) \; [K_g \; \text{cal}/k_g]$$

where $\mu = D_B$, weight of injection water/D_K, weight of water evaporated to steam or the relative quantity of water for spray injection before final convection superheater stages.

Observations of the screen showed that slagging was not entirely eliminated. A thin layer of fly ash remained. However, the formation of large deposits of slag was prevented.

The effectiveness of vibration cleaning can be evaluated by comparing the test results for the increase in heat contents of the steam against periods of operation when the vibrators were not used.

A comparison was made during the period 35–370 hr of boiler operation when tests were selected for similar loads and furnace excess air.

Fig. 4 shows the relationship of Δ_i^{rel} of the screen superheater during operation of the boiler with periods of on and off of the vibrational device. It must be remembered that screens 1–8 and 2–7 were systematically cleaned by hand so that the relationship, Table I, does not completely describe the effectiveness of vibration cleaning. Screen tube No. 5, being inaccessible to hand cleaning and having the smallest amplitude (0.2 mm), is included in Fig. 4 as a comparison of actual minimum value for vibrational cleaning for the boiler in question.

Fig. 5 presents comparison for screen No. 1 which compares hand and vibrational cleaning. The graph indicates that heat absorption is appreciably reduced with an increase in the number of hours of boiler operation and without vibrational cleaning despite an increase in temperature of the gases entering the screen superheater. If, however, the furnace gases had remained constant in temperature, the gradient shown in Figs. 4 and 5 would have been sharper.

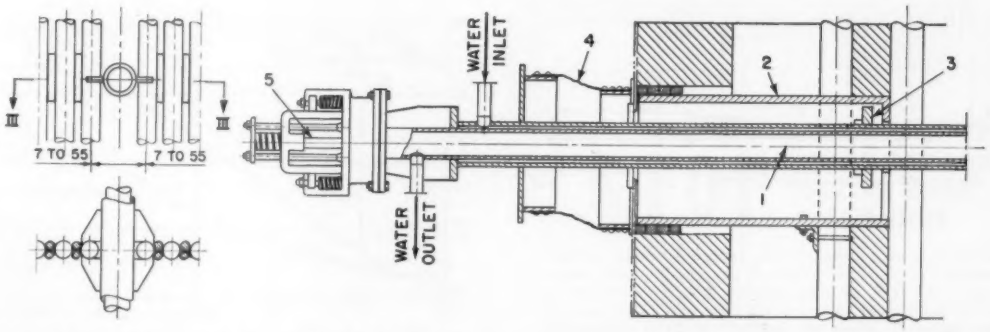

Fig. 2—Details of the vibration equipment—Assembly I, Fig. 2, facing page, shows vibrator position in slag screen and Assembly II shows the length view of the vibrating rod. Here, above, the parts are identified at the entrance to the furnace casing. (1) The cooling rod (note the water feed to the radial cooling system), (2) The cast iron shell, (3) The cast iron flange, (4) The sealing sleeve, (5) The vibrator itself, (6) The counterweight for supporting the vibrating rod assembly, Assembly II, facing page.

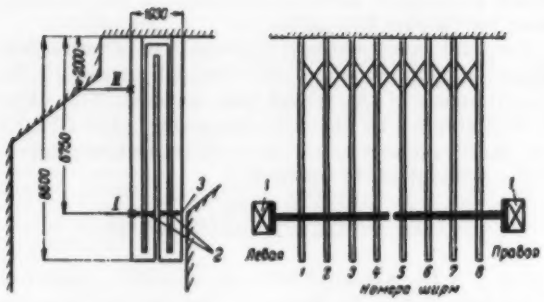

Fig. 3—Location points where vibration amplitude has been measured are to the right of the Roman numerals above and appear as small x's. Amplitude is measured in the directed axis of the cooling currents on the screen tubes. The series of numbers below the tubes on the cross-section drawing right represent the number of screens. The Arabic numbers 2 and 3 in left side of drawing and the Arabic number 1 on each side of the cross-sectional view represent the following: No. 1—the vibrator, No. 2—Cooling currents, No. 3—The welds

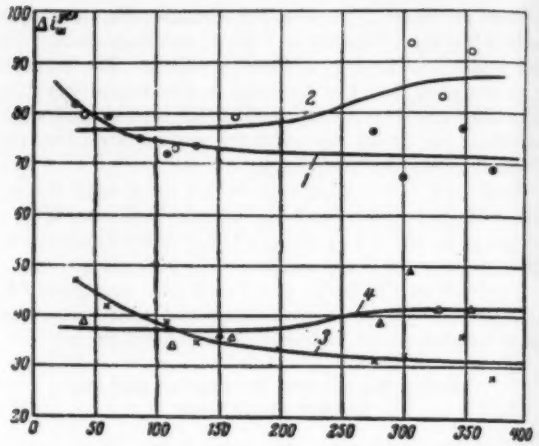

Fig. 4—Relation between steam heat content relative increase Δ_i^{rel} in the superheater screen under boiler operation (where D, tons of steam per hr, varies from 151 to 157 and where α coeff of excess air, varies from 1.17 to 1.26. Curve 1, Operating without vibration cleaning; Curve 2, Operating with regular vibration cleaning; Curve 3, Screen No. 5 without vibration cleaning; Curve 4, Screen 5 with regular vibration cleaning

In the event of a reduction in furnace heat absorption from slagging the gas temperature would have increased and partly compensated for the heat absorption loss from this increase in slagging to hold Δ_i^{rel} almost constant and hence make it independent of boiler operating time. For the boiler under test 15 days after operation furnace conditions became stable. A comparison of two screen slagging conditions with or without vibration shows, Figs. 4 and 5, that after 7–8 days there is a difference between the corresponding Δ_i^{rel}. But after fifteen days this Δ_i^{rel} difference remains stable.

Fig. 6 shows the comparative difference in magnitude as expressed as a function of operating time:

$$\delta = \Delta_i'^{rel} - \Delta_i^{rel}\ 100 \text{ per cent}$$

where $\Delta_i'^{rel}$ and Δ_i^{rel} are the relative increases in heat contents of the steam while operating with and without the vibrators. The values were derived by comparing the curves in Figs. 4 and 5 and characterizing in the first approximation. This relationship makes it possible to evaluate the effectiveness of the vibrating device. On the average the increase in heat absorption amounts to 20–25 per cent when the vibrator is employed as against a manual cleaning system.

An analysis of the test data with reference to heat absorption shows that the effectiveness of vibration cleaning depends upon vibration amplitude (Fig. 7). This shows that comparative heat absorption of four screen tubes (1-3-5-7), from which direct measurements of temperature and steam flow were taken, decreases the farther removed from the source of vibration and the smaller the amplitude of vibration. Expressed in terms of falling value:

$$v = \frac{Q}{Q_{ar}}$$

where:

Q = heat absorbed in a given screen
Q_{ar} = heat absorbed in all screens, averaged

Metal Operating Specifications

After an operational period of 2625 hr with regular vibrational cleaning an inspection of the screen tubes and

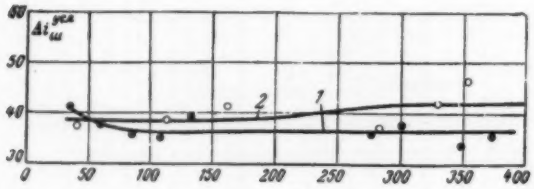

Fig. 5—Relationship between the relative increase of steam heat content Δ_i^{rel} in screen No. 1 against boiler operation. Curve 1, Operating with manual cleaning in the 34 to 372 hr interval; Curve 2, Operating with regular vibration cleaning, 41 to 353 hr.

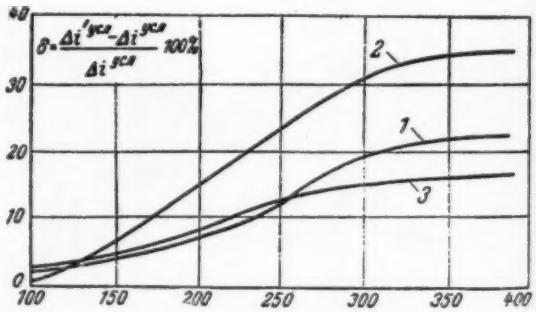

Fig. 6—Relationship between the relative effectiveness of vibration cleaning and boiler operation. Curve 1, Screen superheater; Curve 2, Screen No. 5; Curve 3, Screen No. 1

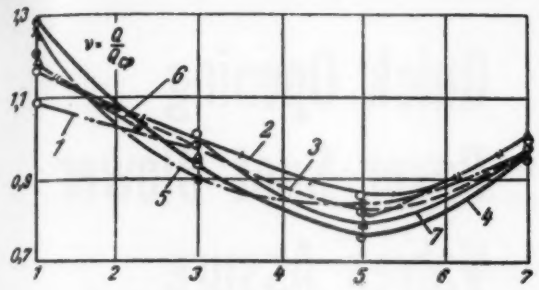

Fig. 7—Comparison of heat absorption of the screens during the tests while the vibration apparatus is operating. Curve 1, Tests of Dec. 18; Curve 2, Tests of Dec. 19; Curve 3, Tests of Dec. 20; Curve 4, Tests of Dec. 21; Curve 5, Tests of Dec. 22; Curve 6, Tests of Dec. 23; Curve 7, Tests of Dec. 24

the vibrational device was made. Specimen samples were also taken. The visual inspection showed that the screens and the vibrational device to be in very good condition and that the initial provisions to allow for temperature expansion of the superheater were correct. The metal samples were found to be in poor condition in the dynamic and thermal areas. The sample points are shown in Fig. 2.

The four months of operating experience with the vibrational device is insufficient for a final opinion. Nevertheless, examination after a period of operation (700.10^3 full cycles of dynamic vibrations) makes it possible to detect the general tendency of the metal structure change.

A mechanical analysis of the properties of the superheater tube metal (15 X M) showed no change. Micrometer and macrometer examination of the samples revealed that the basic metals were in good condition and that no structural changes or cracks were found except in the sample which was attributed to poor welding. Several micro-sections showed poor welding. It is necessary that special attention to welding quality be given when mounting vibration equipment.

Conclusions

Vibration cleaning is one of the most effective means of insuring extended slag-free operation and substantially reducing ash deposits in the screen superheater. This, of course, increases the heat absorption of the screen superheater.

The use of vibrators makes it possible to establish the surface of the screen superheater and maintain it in a clean condition while operating with gas temperatures of 1350–1400 C.

It is also possible to improve the economics of the boiler and insure full automatic mechanical cleaning.

Instrument Society of America Elects Offices

Officers for the year 1961–62 were elected today by the Instrument Society of America, meeting here in conjunction with the Society's 16th Annual Instrument-Automation Conference & Exhibit. The Conference is being held at the Biltmore Hotel, while the Exhibit is being stated in Memorial Sports Arena.

Assuming the presidency of the Society after serving a year as President-elect-Secretary, is Philip A. Sprague, Michigan City, Ind., president of The Hays Corp. of that city. He succeeds Dr. Ralph H. Tripp, Huntington, N. Y., assistant director, Flight Test, Grumman Aircraft Engineering Corp., Bethpage, L. I., N. Y.

Nathan Cohn, Philadelphia, vice-president of Leeds & Northrup Co., was named President-elect-Secretary, moving him into position for the post of the 1962–63 president of the Society.

Named as Vice-president-elect of ISA's Standards & Practices Department, is John R. Mahoney, Oak Ridge, Tenn., a superintendent at the Union Carbide Nuclear Plant there.

Dr. Benjamin W. Thomas, director of Instrumentation Physics Research, Texas Butadiene & Chemical Corp., Baytown, Tex., was chosen Vice-president-elect of the Technical Department of the Society.

Six District Vice-presidents of the Society were elected, each for a two-year term.

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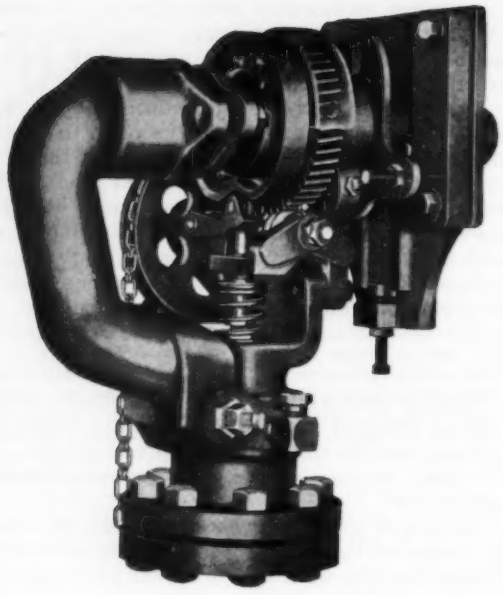

Quick Opening Bayer Soot Blower Valves Assure

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- minimum steam consumption
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The Bayer Balanced Valved Soot Blower is a single-chain operated design that assures precise sequential operation of the valve and element. *Only* after the start of full steam flow does element rotation commence—a feature which provides positive and efficient cleaning over the entire arc. . .without wasting steam.

The Bayer Soot Blower is simply operated by a pull on the chain which opens the cam-actuated valve. Continued pulling of the chain slowly rotates the element through its cleaning arc, at the end of which the valve automatically closes.

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- single chain operation
- individual elements adjustable for high pressure service by orifice plate valve
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- selected gear ratios for optimum rate of element rotation
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For further information contact the Bayer representative nearest you. He is an experienced engineer, qualified to service Bayer Soot Blowers.

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The July issue of COMBUSTION carried the article "Repeated Acid Cleaning of Boilers" by J. K. Rice of Cyrus Wm. Rice & Co. In it Mr. Rice commented on a range of different experiences with acid cleaning and concluded that "the evidence points strongly to deposits as a major factor in determining the extent of corrosion with each cleaning." As was expected, this drew the fire of a number of the leading water treatment specialists and we print here their comments.

Repeated Acid Cleaning of Boilers

I. B. DICK

Asst. Chief Chemical Engineer, Consolidated Edison Co. of New York, Inc.

"I have read with great interest the article in the July 1961 issue of your esteemed magazine, titled "Repeated Acid Cleaning of Boilers" by J. K. Rice. I say I read this article with great interest advisedly because I believe I have probably had a hand in the chemical cleaning of more pieces of power plant equipment than any other utility employee in the United States. The total is now 1065, of which 641 represent boiler cleanings. We have one 1800 psi boiler that has been acid cleaned 26 times, and a number of others in that general pressure range which have been cleaned approximately 20 times each.

"I find some of the observations in Mr. Rice's paper to be most disturbing. I think we all must concede that repeated chemical cleaning of boilers will result in attack upon internally welded drum baffles and on bolts and nuts used to hold internal assemblies in place. It is understood that these materials are usually not of the highest specification, and in no case is any effort made to relieve stresses in them after fabrication. We have found it necessary to replace bolts and nuts and in some cases weldments of such drum internal structures occasionally. We believe this is a small cost to pay for chemical cleaning. We have also observed the roughening of tube flares, and to a lesser extent of tube rolls. However, in only one case so far have these become sufficiently pronounced to be cause for any concern, and since this boiler is identical with one other and very similar to two others in our system which do not show such severe effect, we are inclined to believe that the tube metal in this case was the determining factor.

"In no case have we seen anything resembling Mr. Rice's Fig. 3, which is labeled a boiler tube after 27 acid cleanings. As a matter of fact, we believed up until the time we read Mr. Rice's paper that our 1800 psi boiler which had been cleaned 26 times held the record. This boiler has surely disclosed nothing like Mr. Rice's photograph. We have seen economizer tubes of low-pressure boilers which operated without deaeration that looked very much like this figure after chemical cleaning. However, I do not believe we could attribute the condition to the chemical cleaning.

"I view with amazement Mr. Rice's photographs, Figs. 4 to 13, inclusive. I note that in describing this experiment the author has not given us the prescription for the acid solution that he used in the cleaning. It is a little difficult, therefore, to criticize constructively. I can only say that

I. B. DICK

(continued)

in our case in actual boilers with the background of experience that we have indicated we have not seen these effects.

"With all due respect to the paper presented, I would like to ask this question: How would the author propose to clean a modern high-pressure boiler if it were not done with inhibited acid?"

J. P. ENGLE

Laboratory Group Leader, Dow Industrial Service, Div. of Dow Chemical Co.

"My reactions and comments are necessarily tempered somewhat in that the method of test procedure and experimental apparatus used by Mr. Rice are not entirely clear in my mind. By proper selection of procedure and laboratory equipment, data can be obtained from a laboratory program which are meaningful, indicative of trends and therefore helpful. On the other hand, faulty procedure and violation of fundamental principles during execution of the program can and will produce data from which, only false conclusions are likely to be derived. It is with reference to the last two items and particularly the latter, that I think Mr. Rice has erred.

"One fundamental principle violated pertains to crevice effects. U. R. Evans in the 1960 edition of "*The Corrosion And Oxidation Of Metals*" relates work done to delineate the corrosion mechanisms in such cases. It is pointed out that a glass rod placed on a steel surface produced corrosion of the steel at the crevice in N/20 sodium carbonate. Reference is also made to corrosion observed beneath sand grains in brass condenser tubes carrying cooling water. Evidence of failure to head this principle or to recognize it is apparent from examination of Figures Nos. 4 through 13 of Mr. Rice's article.

"Consider Fig. No. 4 which shows a very seriously corroded hemispherical line of demarcation. I assume this hemispherical line represents the area of contact between the flat surface of the specimen and the polyethylene tube heat sealed to the surface. Notice that the attack on the metal is confined to the crevice junction (the hemispherical line). No deposit was added in this test, severe attack is observed, yet in his words, the purpose of the test was "to learn if different deposits—might affect the amount of acid attack." It is apparent from this test, without deposit, that crevice corrosion is also important. It is safe to assume that the same pattern of corrosion would have been produced by many other types of corrodent other than inhibited hydrochloric acid. Water, salt water, alkaline solutions—all would have produced the same pattern but to varying degree-with no deposit present.

"Let's examine Fig. No. 11 where only the magnetite was placed on the surface prior to the inhibited acid. The crevice effect discussed above is evident (as in all Figures Nos. 4 through 13). By placing the deposit on the surface, we have created multitudinous crevice areas which is not typical of mill scale (Fe_3O_4) formed *in situ*. A considerable tonnage of steel is pickled daily in the U. S. to remove mill scale (Fe_3O_4) and this process does not leave the surface in a condition one would expect to find based on this test. If we want to study the effect of mill scale removal or the removal of magnetite from boiler surfaces, we must duplicate the conditions. This can be done by oxidation of steel specimens in an atmosphere of steam which forms magnetite *in situ*. The magnetite film is continuous and integral: the removal of such films does not leave the metal surface corroded, roughened and scuffed.

"I would not want to imply that the presence of deposits on metal surfaces does not affect inhibition during cleaning. They admittedly do play a significant role; this we have studied for many years. They do not play the role portrayed in the photographs by Mr. Rice for reasons I have pointed out. The procurement of data by an investigator must be obtained by reliable methods. Management and technical personnel rely on data reported in current literature for guidance. It is unfortunate that this aspersion has been cast on chemical cleaning to these people. Research and development has done much in the last ten years to make a science of this maintenance operation which has barely passed its thirtieth birthday. If we should suddenly have to revert to manual cleaning of modern high pressure boilers, many of us would be without electric power for extended periods of time in all probability."

V. J. CALISE

General Sales Manager, Graver Water Conditioning Co.

"The author has provided laboratory evidence to prove the point which has been both known and guessed at in the industry that the nature, extent and location of deposits is a major factor in determining the extent of corrosion caused by each cleaning of a boiler or boiler cycle. This evidence would further indicate that some caution must be introduced into the considerations in favor of periodic and frequent acid cleanings and suggests additional study in the industry to pinpoint the relationship between deposit type, location of deposit and the effect of acid cleaning in producing boiler metal corrosion.

"While it may be suspect for one engaged in the business of external treatment equipment design to take such a position, we must nevertheless agree with Jim Rice that if the cost of loss of metal in the boiler is figured into the cleaning cost, external treatment processes are favored. However, we should also add several other considerations in this regard. Firstly, the cost of keeping a central station closed cycle purified or clean of total dissolved solids and/or crud is quite nominal today as compared to several years ago, when our early concepts of equipment design for condensate scavenging were first applied (Refs. 1 and 2). Secondly, the cost of external treatment of makeup regardless of process has been a more or less constant quantity over the years. Thirdly, the improvement in knowledge and application of proper internal chemical treatment methods based on the "zero or low solids" treatment with ammonia or hydrazine as a part of the treatment has substantially reduced the internal cycle corrosion and deposits problem for high pressure boilers. Lastly, I am always horrified by this fact when I articulate or write it but it is nevertheless true; namely that most central station closed-cycle power plants never have a base load life of more than 8–12 years, before they are relegated to standby operation and the question to be asked is—does anyone really design a high pressure cycle for the on and off standby operation that inevitably comes about at some later period on all such plants since new and more efficient units are always coming along to replace them? These standby conditions really try the design and operating mettle of the power engineers involved and are the cause of many difficulties with high pressure boilers and boiler cycles.

"We feel that Jim Rice has done the industry a service in pointing the finger at a problem that has obviously existed in the past and has required some work and fresh thinking to indicate what may be happening when boilers are acid cleaned too often or acid cleaned without regard to the nature, location and extent of deposit to be removed by the cleaning process."

Ref. 1. Graver Water Conditioning Co. technical reprint. T-182, "The Place of External Regeneration in the Design of High Rate Condensate Scavenging Systems."
Ref. 2. Graver Water Conditioning Co. technical reprint. T-185, "Progress in Condensate Scavenging-Operating Results from Three Central Stations."

T. J. FINNEGAN

Chemical Engineer, Niagara Mohawk Power Corp.

"The most startling conclusion made by Mr. Rice is that in evaluating the cost of acid cleaning of boilers one-twentieth of the cost of a complete retubing should be included. Since the principal reason for acid cleaning is to prevent tube failures, that is to eliminate the necessity of tube replacement, one might ask if it would not be better to keep the boiler extremely clean in operation by having as low a percentage of makeup as possible and that of the purest water obtainable; using little or no internal treatment; striving for complete deaeration; blowing down frequently to remove any sludge that might form; and not acid cleaning at all. Such considerations as the elimination of copper alloy heat exchanger tubes might be part of such a program. If in spite of the rigid procedure directed to produce a clean boiler, corrosive tube failures occurred anyhow, and it was noted that deposits were associated with these failures (as is probably usually the case), it could be decided that like all ideals that of a perfectly clean boiler is not quite obtainable and the boiler should be given an acid cleaning to restore its pristine condition.

"Unfortunately, when a boiler is having corrosive tube failures, the deposits are crusty Fe_3O_4 containing more or less copper and are not soluble in dilute hydrochloric acid at the relatively low temperature of acid cleaning.

T. J. FINNEGAN

(continued)

Therefore, the acid might not be more than slightly helpful unless it was accompanied by "turbining" to remove the heavy "scabs" but unfortunately, the tubes in a modern boiler are not accessible for turbining.

"With full recognition then that acid cleaning is not something to be casually adopted because it might be true as Mr. Rice concludes that after twenty cleanings the boiler should be retubed, it nevertheless almost becomes a necessity as preventive medicine. Following this principle, the boiler could be cleaned before the deposits reach the crusty scaly condition. Lest this idea be oversimplified, however, it should be remembered that many such deposits are the result and not the cause of tube corrosion. Still, it is reasonable to assume that elimination of Fe_3O_4 in the loosely deposited condition might remove a "pre-malignant" feature and save many tubes.

"The practical procedure would be to select a suitable frequency for acid cleaning. To acid clean once a year or even more frequently flaunts Mr. Rice's warning unless the boiler is in serious tube trouble, and this is not within the scope of an established preventive program. To wait five years or more might make acid cleaning a useless expense. If a boiler can go that long without cleaning, it probably has some sort of immunity. This is not a flippant remark. It is well known that some boilers never seem to have trouble while an identical one in the same plant, operated in the same manner might have many forced outages.

"A suggestion might be to review the boiler's recent history every two years. If boiler water and feed water analyses and internal inspections show any signs of potential trouble, the boiler might be acid cleaned. Some of these signs are periods of black water, difficulty in maintaining treatment levels if treatment is used, inexplicable changes in steam conductivity and difficulty in draining the boiler. If everything is all right, the cleaning might be omitted for one year but in any event, the boiler should be cleaned at least every three years. If Mr. Rice's formula is correct, this will mean retubing in forty years. This is beyond the design life of the boiler and an acceptable risk.

"His attempts to show possible causes of corrosion are interesting even though based on very simple laboratory experiments because they illustrate the lack of fundamental knowledge of the corrosion of steel by aqueous media, an ironical fact in a world where so much has been learned about subatomic reactions and phenomena of outer space.

"A word of warning about weldments. All welds are potential locations of corrosion because all welds, no matter how carefully made, nor how free of foreign influences such as backing rings, beads, or scale have the elements of a differential electrode cell because it is impossible to produce a weld which is structurally identical to the neighboring normalized boiler metal. The potential difference between the two electrodes is not high, the boiler water is low in conductivity but nevertheless a risk is present. It is, therefore, important not to aggravate the condition by permitting any degree of dirtiness at the weld."

J. D. RISTROPH

Manager of Power Production, Virginia Electric and Power Co.

"The comments of Mr. Rice are thought-provoking and indicate a need for study and evaluation of additional factors in the field of chemical cleaning of equipment.

"While it has been common practice to analyze deposits for solubility prior to cleaning procedures, perhaps we need to further study the by-products of the cleaning reaction. This discussor performed many experiments in the earlier days of chemical cleaning relative to ferric by-products and their corrosive action. It is quite obvious that the solution cannot be expressed in general terms—most deposits will vary in chemical constituents, even if to a minor degree.

"As a corollary to the above, it is equally apparent that we need further research in the field of inhibitors. We should also recognize that such research is not free—the cost must be included in the overall price charged for a chemical cleaning service. Certain of the larger chemical cleaning services are now bearing this burden exclusively.

"As a matter of personal opinion, chemical cleaning is no substitute for proper water treatment. (This excludes the mill-scale or similar cleaning

J. D. RISTROPH
(continued)

procedures.) One of the greatest fallacies of present-day water treatment is the establishment of rigid standards of water treatment by general office or station technical people, with extremely lax applications of these standards in the field—chiefly caused by infrequent testing or inadequately trained personnel.

"This lack of adequate testing and/or planning applies also to chemical cleaning procedures in the field. It is felt that many difficulties ascribed to chemical cleaning can be more properly laid to improper or inadequate cleaning procedures in the field."

C. M. LOUCKS, PH.D.

Consulting Chemist

"I did not mean to solicit an invitation to comment on Jim Rice's paper but since it has stirred up some discussion I am glad to explain how these "corrosion situations" have appeared to a chemist who has been in the big middle of many of them during 18 years in the so-called "acid-cleaning" business.

"The sequence of events was almost without variation. Evidence of corrosion would be observed in a boiler after chemical cleaning. Tube specimens would be removed and sent to laboratories of acid service company, water treating consultant, and boiler manufacturer. I would receive a report from our laboratory full of pretty macro and micro pictures and the conclusion, "We are not guilty." Armed with the report, I would attend a conference of from three to thirty people including "experts" of various sorts. The meeting would be called to order and the acting chairman usually gave me, as a representative of the last party at the scene of the crime, the right to speak first.

"So I would present the report with careful emphasis on such scientific evidence as was available to draw deductions from. Then came the stoney stares, the awkward silence, and the looks of disbelief on many faces that the accused dare to deny the guilt. I have been through this rigamarole so many times it could become amusing, if it weren't so serious. At one such conference, a man, throughout the morning and during lunch, kept saying "But you can't eliminate the human element."

"He was more profoundly wise than he intended to be. You can't eliminate the human element, not from the cause of the corrosion, but from the almost comic-opera attempt at an investigation of the cause. Unfortunately in many cases the evidence one has is meager, much possible evidence has been destroyed by the very act of acid-cleaning. The corroded victim lies naked for everyone to see and the acid-cleaner stands at the scene with a dangerous weapon—acid—in his hand. Any way shouldn't he be accused, everyone knows that hydrochloric acid is corrosive. The service company admits it is corrosive, but just a wee bit. Nice laboratory tests show inhibited acid will dissolve only a fraction of a mil of steel at typical service and exposure times. At the conference table little actual evidence is to be had, so the customer relies on "expert" opinions. And the "experts," with monotonous regularity say, "It is acid corrosion." I have yet to see one of them furnish concrete, scientific evidence to support the opinion. The meager defense of the accused, even when it contains some semblance of scientific evidence, falls on deaf ears. One might suppose the acid-cleaners invented corrosion and no other cause need be considered.

"But this is letting off a little steam over a situation that, as the man said, involves the "human element" instead of cold, impersonal, scientific procedures and deductions. My interest in Mr. Rice's work is not to defend it as the ultimate in scientific procedure and deduction, but it does point to phenomena which, I believe, have much more to do with abnormal boiler corrosion than all the inhibitor tests put together. The solid phases which foul steel surfaces, and which are to be removed by inhibited acid, may have a profound effect on corrosion of the steel surfaces during the very act of removal. In many cases, I suspect from my own observations in the laboratory and in the field, certain solid phases may contribute to corrosion rates that are many fold greater than the nice neat little numbers we point to with pride.

"And, it seems apparent, this type of corrosion is non-uniform, which also makes it more conspicuous. Corrosion must be non-uniform to be conspicu-

C. M. LOUCKS, PH.D.

(continued)

ous. If five per cent HCl could be put in a perfectly clean boiler and caused to spend itself *uniformly* on the metal surfaces, do you know how much metal loss there would be? Everyone would exclaim at the nice, clean appearance of the surfaces.

"The corrosion by acid alone, that is conspicuous, is the non-uniform corrosion on tube ends *and* acorn nuts, at welds and discontinuities in metal structure. This corrosion induced by the presence of certain solid phases during exposure to acid may be highly localized. The phenomenon is not a simple one and it has received practically no attention in the midst of the "You did!" "I didn't!" drama. I am aware that this argument implies that the use of acid has, in these instances, contributed to the evidence of corrosion. I have no doubt of that and have not failed to point out that this may well be the case. But it serves little purpose to repeat the uninspired testimony "It is acid corrosion." Let's find out more about the effect of solid phases on corrosion during and after cleaning. The acid-cleaner did not put the solid phases there and, in many instances, has no way of knowing whether potentially dangerous solid phases exist. So let's get off the acid-cleaner's back in these situations. He is trying to do his job just as carefully as you try to do yours. And few service groups can match his efforts in hard work, long hours and sacrifice of personal comforts. His service has saved many maintenance dollars and restored many items of equipment to useful operating condition.

"If there is a corrosion problem involving the solid phases, as Mr. Rice's paper suggests, why don't we stop pointing fingers or sticking the head in the sand. If the paper stimulates not only controversy, but further scientific investigation, it will have served a useful purpose. We need less 'human element' and more facts."

J. M. DECKER

Water Systems Engineer, The Detroit Edison Co.

"The illustrations in J. K. Rice's paper, "Repeated Acid Cleaning of Boilers," showing damage attributed to many and frequent acid cleanings are alarming. In our experience at The Detroit Edison Co., however, we have not observed damage resembling that shown by Mr. Rice, possibly because we have not to date cleaned any one boiler more than three times.

"Our current practice is to acid clean boilers after 4 to 6 year operating periods. At that frequency approximately 50 years will have elapsed before 12 cleanings have been performed. Perhaps by that time, we would have damage such as shown in Fig. 1 of the paper. This should not be of great concern, however, since it is doubtful if the boilers will be cleaned 12 times or be in service for 50 years.

"Tube damage, to the extent shown in Fig. 2 after six cleanings, it seems would have been evident after the third cleaning. We have not experienced, to our knowledge, such damage. Could it be that the damage shown in Fig. 2 was caused by corrosion associated with high heat input rates in the area of the welds, and that acid cleaning removed the corrosion products exposing the pits? It appears that a considerable amount of pitting has occurred in parts of the tube that were unaffected by welding, indicating that the tube may have become pitted in service and that these pits, too, were exposed as a result of acid cleaning. Pitting may have been severe in the weld-affected area during service, thus accounting for the greater metal losses there.

"The samples used in the simulated cleaning tests (Fig. 4 through 12) show little evidence of pitting, but seem to have been more or less generally attacked by the acid used in the tests. This also leads one to the conclusion that the pitting of the tube sections shown in Fig. 2 and 3 may have occurred in service and not during acid cleaning.

"Regardless of the cause of the pits in the tubes, I am in complete agreement with Mr. Rice's view that chemical cleaning is a poor substitute for adequate feedwater and boiler water treatment. Good water treatment should be provided and maintained in order to keep boilers clean. If this is done boilers will operate satisfactorily with infrequent acid cleanings. If a boiler must be cleaned more frequently than once per year, it seems there must be something wrong with water conditions or that the boiler is improperly designed making frequent cleaning necessary."

S. F. Whirl

Chemical Operating Engineer
Duquesne Light Co.

"We here at the Duquesne Light Company have had no experience with repeated acid cleaning of boilers. Therefore, any comment I might make would not be based on experience, but rather on opinion and conjecture. Why it is necessary, or thought to be necessary for some to acid clean often and repeatedly, while others like ourselves do not appear to be faced with this problem may depend on many factors. I do not believe it to be a matter of pure and simple luck.

"Many companies are faced with the serious problem of metal cracking known by various names such as hydrogen embrittlement, oxidation embrittlement, or hydrogen damage. This phenomenon is far from being understood, but consensus of opinion seems to be that repeated acid cleanings are helpful in avoiding it. Research is definitely needed in this field and the ASME Joint Research Committee on Boiler Feedwater Studies is striving desperately to get a corrosion research program under way. Let's all back it.

"Mr. Rice is to be commended for publishing this interesting work which presents a challenge for further study to those associated with "acid cleaning corrosion"; and also to those interested in preboiler treatment for the prevention of corrosion. It is noted that Mr. Rice's experiments were conducted using a single stage treatment of inhibited 5 per cent hydrochloric acid solution. It would be interesting to learn whether the same kind of damage would be incurred if a two stage treatment were employed, i.e., an initial treatment for the removal of copper, followed by inhibited acid for the removal of iron."

Author's Closure

I wish to make clear at the very outset of this reply something that I must not have made clear in the original:

The corrosion that occurs during acid cleaning is the result of joint action of the deposit, the solvent, and the inhibitor on the particular metal surface involved and that the deposit may affect the extent of corrosion equally as much as solvent strength, inhibitor efficiency, or the steel structure.

I am not in any way suggesting, as some felt, that acid cleaning of boilers should be abandoned. I simply say that *repeated* acid cleaning may cause such intolerable corrosion that the effects of the deposit to be removed must be known in advance to predict the corrosion effects from repeated acid cleaning.

Dr. Loucks summed up this position better than I when he replied that from his long observations in the laboratory and in the field certain solid phases (which foul steel surfaces) may contribute to corrosion rates that are many fold greater than the nice, neat little numbers that we point to with pride.

J. C. Ristroph makes an important point that is too often overlooked when quotations for solvents are compared: the research behind each gallon of solvent costs money and must be paid for.

I would add that when contemplating repeated acid cleaning, the cost of a solvent that includes adequate research may be the lowest cost in the long run. Tom Finnegan's elaboration on my rough rule of thumb of $^1/_{20}$th the cost of retubing as a hidden cost of the acid cleaning develops many interesting points. I must caution though that this rough rule was intended only to assist in evaluating the economics of alternate treatment processes. Twenty cleanings are not intended as a hard and fast limit since, as I. B. Dick points out in his comments, he has a boiler that has been cleaned twenty-six times without significant corrosive attack and several that have been cleaned twenty times without serious attack.

Dick asked "how would the author propose to clean a modern, high pressure boiler if not with inhibited acid?"

I am sure this question, with only the word "manually" substituted for "inhibited acid" was asked thirty or more years ago. I am afraid that my only reply is the sentence with which I concluded my article—"the evidence shows the need for more study of repeated acid cleaning."

Vince Calise touched on a point that is a fit subject for a symposium by itself—how to handle high pressure boilers when they go into peaking service. Strangely enough, frequent repeated chemical cleaning may prove to be the economic answer in such cases.

I appreciated J. P. Engle's criticism of the technique used in obtaining the data. I realize only too well that the experiment was not rigorously conducted. I am sorry however that Engle did not present the data that he indicates he has long possessed on the effect of deposits on the corrosion rate during acid cleaning, which effect he further admits is significant.

While I agree with Engle that the crevice attack around the extreme edge of the specimens that I show bears no relation to deposits (he points out Fig. 4 had no added deposits yet experienced crevice attack), I cannot quite understand how he feels that this has a bearing on the obvious difference between Figs. 4, and 7, and 12.

His citation of Evans on crevice attack and on observed corrosion beneath grains of sand on a tube surface, I feel supports rather than violates the conclusions that I have drawn: that deposits can cause corrosion rates during acid cleaning to be many times higher than in the absence of deposits. Eagle's digression to "mill scale" is in part irrelevant, since mill scale removal is hardly considered part of repeated acid cleaning. If one considers, however, magnetite films grown in place by direct iron water or iron steam reaction, then certainly his comments on uniformity apply and I have no quarrel with his conclusions. I was concerned with magnetite that had deposited from the water and thus had originated elsewhere. In high pressure boiler cleaning such magnetite deposit is at least as prevalent as the oxides formed in place.

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16	12½% of wall	.003 sq. inches
14 and 13	12½% of wall	.004 sq. inches
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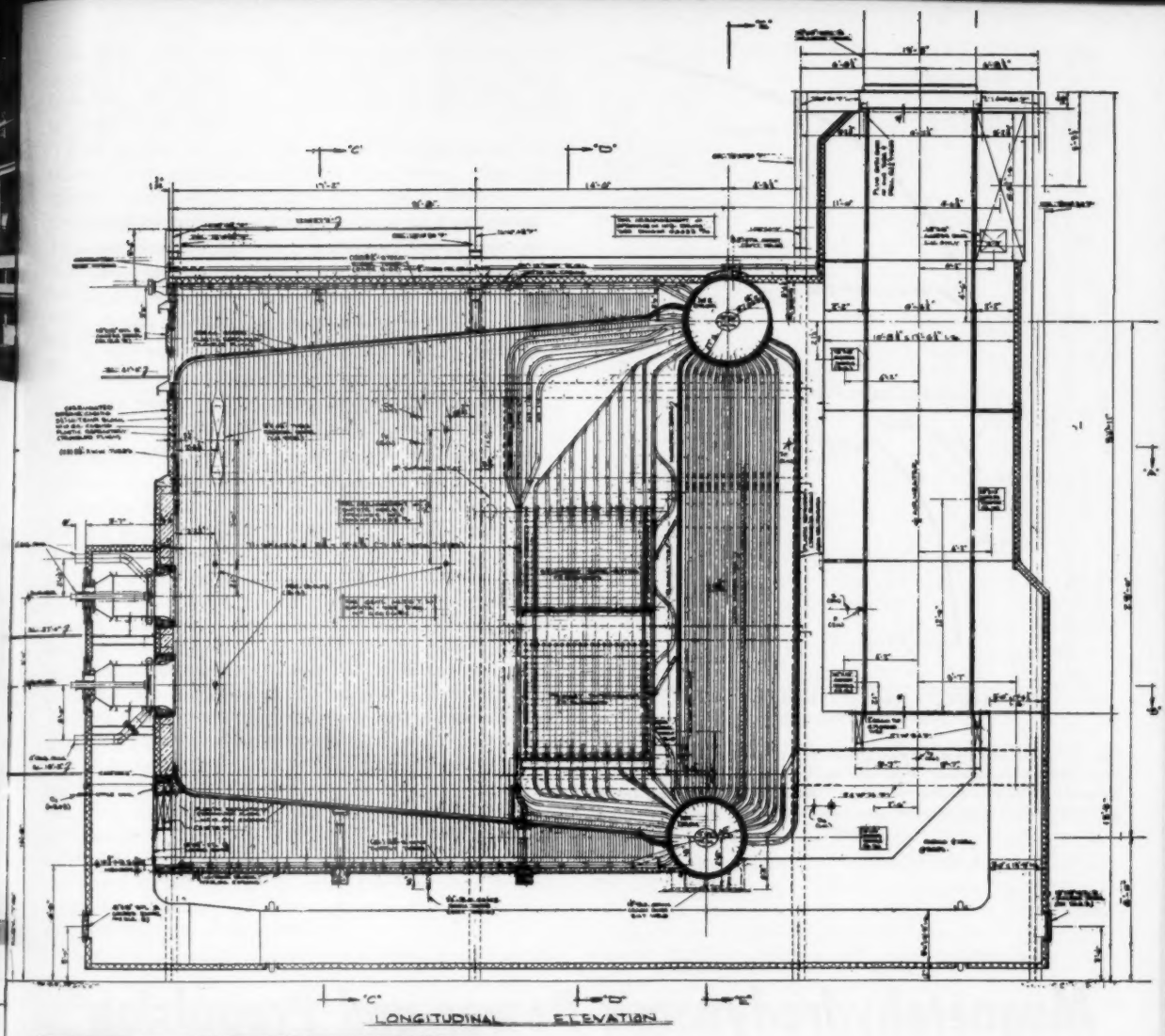

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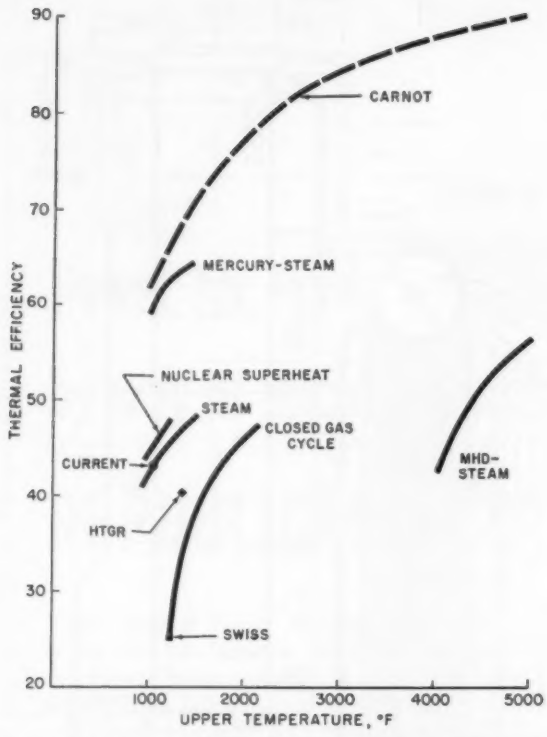

Fig. 1—Family of curves, above, shows the theoretical efficiencies for steam, gas, mercury-steam, MHD and the High Temperature Gas-Cooled Reactor (HTGR) plus nuclear superheat. Note MHD and mercury-steam are the only ones promising over 50 per cent efficiency. Hence the interest in MHD

During the past year, the principles of magnetohydrodynamic power generation and propulsion have been experimentally verified. As yet, no practical generators have been demonstrated. For fuel burning generators, the materials lifetime and gas electrical conductivity must be increased without a sacrifice of efficiency. For propulsion, very high specific impulses have been successfully demonstrated for almost every type of device. Their compact size offers a distinct advantage over ion devices, and thus additional research appears to be justified.

Editor's Note: In this paper, the significant progress in each field is reviewed, compared, and analyzed but for our readers interests only those pertaining to bulk power generation are reported.

Magnetohydrodynamic Power and Propulsion*

By GEORGE W. SUTTON and PER GLOERSEN†

General Electric Company

THERE are two approaches to MHD power generation which are being pursued. One pertains to the open cycle in which the combustion products are used directly in the MHD generator; the other uses an arbitrary gas in a closed cycle.

Open Cycle MHD Generators

The open cycle MHD generator burns fossil fuel with preheated and/or oxygen enriched air; most of the experimental work is concerned with this concept. Discussed below are central station economics, generating experiments, electrical conductivity experiments, and theoretical cycle studies. These studies are as yet incomplete, and additional data are required to determine whether it is physically possible to construct the required MHD generator to give an overall improvement in fuel utilization and for a reasonable plant investment.

1. Central Station Economics

For bulk power, the common fuel is coal, mainly because it is cheaper by a factor of two than oil at most eastern seaboards. The average cost of electricity is as follows (1):[1]

Fuel	2.8 mil
Salaries & Wages	2.8 mil
Maintenance	1.7 mil
Taxes	4.0 mil
Depreciation	1.7
Profits	3.7
	16.7 mil/kwh

* Presented before the Fourth Biennial Gas Dynamics Symposium, cosponsored by the American Rocket Society and Northwestern Univ. held at Northwestern, Aug. 23-25, 1961, and abstracted here.

† Space Sciences Laboratory.

[1] Numbers in parentheses refer to similarly numbered entries in the List of References at the close of the article.

Actually, a modern coal burning plant has a fuel cost of only 1.6 mil/kwh. Thus, even if the fuel were free, in future plants the cost of electricity would be reduced by only 10 per cent.

Half of the cost (except for fuel) is concerned with transmission and distribution of this power; thus there is major incentive to use small local generators which can provide power for an individual plant or small locality. An example of this trend is the manufacture by the Swiss of small, *closed* cycle gas turbines which burn low grade fuel (peat) (2). Their thermal efficiency is 25 per cent, which is the average in the United States, but an additional 35 per cent is available in the form of low pressure steam for heating! (*See Fig. 1*)

If the cost and maintenance of such a plant is comparable to that of central station equipment, then the cost of electricity at the smaller plant would be only 9.8 mil per kwh! Perhaps the concept of large central stations is obsolete in regions where fuel is inexpensive.

Nuclear fission power has not yet made a major impact on the power field, nor is it likely to as long as coal is available at five to six dollars per ton. The major problem is the relatively larger investment cost needed for ultra reliability of the components and for safeguards against radiation. The current trend in nuclear power is toward closed gas cycles, which may increase the power output for a given investment. Nuclear fusion is not an economic force at present or even in the near future. Thus, fossil fuel will continue to be the major source of electrical power for many decades. But the consumption of power doubles every ten years; thus in 1971 half the power will be produced by equipment which has not yet been designed. In terms of a 500 mw plant, an additional savings of 10 per cent in fuel utilization will save 0.7 million dollars per year. This should be compared to the plant cost of 70 million; thus it is important to increase efficiency, provided that the plant cost is not significantly increased.

Higher efficiencies require higher temperatures for the working fluid. For steam, higher temperatures require either higher pressures or large amounts of superheat. These have become economical as the price of high temperature steels have decreased. But there may be an upper limit to these developments.

An intriguing possibility is the direct use of the combustion gases in a gas turbine, but here the upper temperature is about 1600 F at present, yielding only a slight improvement in efficiency.

The MHD generator may also use combustion gases, but a minimum of 4000 F is required for the gas temperature to ionize the "seed" material, cesium or potassium. These temperatures are difficult to attain; either oxygen enrichment of the fuel is necessary or a regenerative heater; either approach is expensive. In addition, the gas becomes essentially non-conducting at 4000 F; even after regeneration the exhaust gases contain energy. This gas must be utilized, preferably by making steam to drive the compressors. Because of the higher temperature, a higher overall efficiency can be expected. The maximum is about 56 per cent as compared to 40 per cent obtainable with steam alone. Thus there is ample justification for continuing this research.

This situation is summarized in Fig. 1 which shows theoretical efficiencies for steam, gas, mercury-steam, and MHD-steam cycles (3). Shown also is the High Temperature Gas-Cooled Reactor (HTGR) being built at Peach Bottom, Pa. (4) in which helium is heated to 1380 F and steam at 1000 F and 1450 psi is produced, with an overall efficiency of 40 per cent. The use of fossil fuel to superheat steam from a water cooled nuclear reactor is also shown in Fig. 1.

TABLE I—FUEL BURNING MHD EXPERIMENTS

	Way[6]	Blackman & Jones[7]	Brogan et al.[8]
Fuel	(Diesel)	Kerosene & Ethanol	Kerosene/ Ethanol
Fuel rate, g/sec	118	26	1016
Oxygen rate, g/sec	125	78	
Nitrogen rate, g/sec	2500	3.4	0
Total temperature, ° K	2995	3400	...
Static temperature, ° K	2797	2600	3000
Total Pressure, atm	...	3	...
Static Pressure, atm	1	...	...
Gas Velocity, M/sec	865	10^3	...
Seeding	1% molar K	2% K	1% molar K
Generator size, cm	4.7 × 12.4 × 84	1.25 × 5.1 × 41	7.6 × 23 × 152
Electrode material	...	Tungsten	Graphite
Insulator material	MgO	MgO	Wood
Magnetic field, gauss	14,000	20,000	32,000
Test duration	10 min	30 min	10 sec
Open circuit volts	100	95	550
Max. Power, kw	7.9	1.03	(200)
Power density, w/cm³	1.6	4.0	7.5
Electrical conductivity, ohm^{-1} M^{-1}	26.5	21	(40–60)

The only cycle which shows promise of exceeding 50 per cent efficiency is the MHD-steam cycle (except for the mercury-steam cycle). Thus the current interest in MHD power generation for bulk power.

The main obstacle at present to MHD power generation is the development of materials which have to be in contact with the gases. (Because the magnetic Reynolds number is small, magnetic confinement is impossible.) Either super refractory materials must be developed or else the MHD generator walls must be kept cool; most research on combustion generators is concerned with these problems.

2. Generating Experiments

The first generating experiments used plasma jets as the gas heater with potassium carbonate as the seed material, see review in Ref. 5. Since then, more elaborate experiments have been performed using combustion gases, see Table I. Way (6) has produced almost 10 kw for ten minutes. Nitrogen was added to the mixture to decrease the total temperature to reduce the erosion of the channel walls, which were uncooled.

A somewhat different approach was used by Blackman, Jones, and Demetriades (7) who used water cooled magnesia walls, hence no nitrogen dilution was required. (The 3.4 g/sec of N_2 is from a small plasma jet which served as a flame holder.) However, the water cooled section upstream of the magnet reduced to static temperature below that of Way's. The higher power density is caused primarily by the higher magnetic field strength. In these experiments only 2 per cent of the enthalpy reduction was caused by electrical conversion; the rest was caused by the water cooling.

A much larger experiment was performed by Brogan et al. (8), in which 200 kw has been generated, but for only 10 seconds. The insulation was made of wood;

products of ablation from the wood probably lowered the static temperature and hence the electrical conductivity to a value smaller than 40 ohm^{-1} M^{-1}; the larger power density is primarily due to the larger magnetic field. The open-circuit voltage varied considerably in the axial direction, and the total conversion efficiency was only 1 per cent. In order to increase the efficiency, either the apparatus must be made larger or uncooled, non-ablating walls must be used.

A generating experiment which included both thermal and skin friction losses was performed by Sutton and Robben (9) with nitrogen and potassium carbonate which were heated in a plasma jet. The channel was 1 × 10 × 61 cm, and had 4 graphite electrodes on each side of the channel. The measured electrical conductivity and open circuit voltage were compared with theoretical calculations, see Fig. 2. The open circuit voltage for run No. 31-4 was low, probably due to electrical conduction in the insulator material, which was changed for run No. 31-6. The major uncertainty in these experiments is the electrical conductivity of the gas and insulator. Except for this uncertainty excellent agreement with theory was obtained, which indicates that most of the phenomena is well understood, and no spurious effects occurred. Most of the present work by various investigators is therefore directed toward obtaining more reliable data on the electrical conductivity.

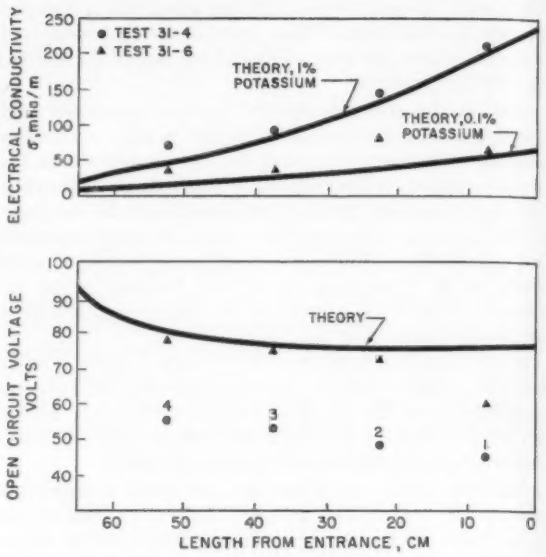

Fig. 2—Open-circuit voltage and electrical conductivity compared with theory

3. Electrical Conductivity Studies

There is still an uncertainty of a factor of three in the conductivity. For example, Mullaney (10) has found that the electron-cross-section of propane-oxygen flames is about 10^{-15} cm^2, which is one-third of the value calculated from cross-sections of the constituents of the products of combustion. Electron attachment to OH does not seem to occur, but definitely does occur with any chlorine which is present. The deduced cross-section of neutral cesium atoms is 13 × 10^{-15} cm^2, and for potassium is only 10^{-15} cm^2. These values are far below the expected values. In general, the ionization seems to follow Saha's equation.

Way (6) used unpublished work of Frost and Phelps for cross-section data, but included the OH attachment. No details were given, but the calculated conductivity was 20 per cent less than the experimental values. However, a 100 deg K error in the temperature measurement could cause a factor of two error in electrical conductivity. The work of Brogan (8) seemed to indicate that the conductivity depends on the mass flow rate.

In order to design a large MHD generator, either better prediction methods for both the electrical conductivity and temperature drop must be developed or one must resort to pilot plant experiments in the 1–20 megawatt range, with conversion efficiencies of 10–20 per cent. In all probability both routes will be traveled.

4. Cycle Analysis

The chief reason for interest in the fuel burning generator is that higher overall efficiencies are obtainable theoretically than from a steam cycle. The improvement in performance is predicted on the practical attainment and confinement of 5000 F combustion temperatures. Commercial fuels give flame temperatures between 3500 F and 4000 F maximum. Thus, preheating and/or oxygen enrichment is required. Both processes are expensive. In addition, the materials problems are more severe, the higher the temperature. Thus, it is advisable to investigate lower temperature operation and its effect on efficiency. This has been done by Luebke (10), and is shown in Fig. 3. Notice that the curve is essentially flat above 5000 R static inlet temperature. As the static temperature decreases, the gain in efficiency decreases rapidly and the duct length increases, so that at 4000 R there is only a 6 per cent gain, but the generator length is 500 ft!

The gain of 18 per cent is not the maximum: for the same inlet static temperature of 5000 R, additional gain can be realized by increasing the pressure ratio, shown in Fig. 4. The curve flattens above 7.5. Note also that the required duct length is 210 ft for 20,000 gauss. If superconducting magnets are used, this length can be reduced to 11 ft! The use of superconducting magnets should be analyzed for its economics but inlet static temperature of 5000 F appears optimum.

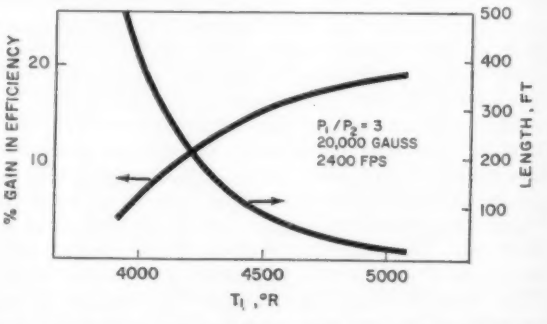

Fig. 3—Gain in cycle efficiency with inlet static temperature along the abscissa for a pressure ratio of 3. Curve with arrow to left is efficiency; arrow to right is duct length

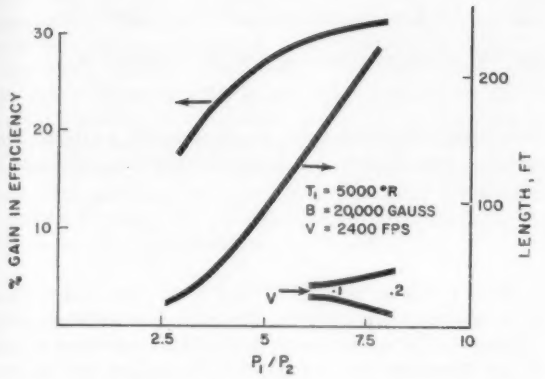

Fig. 4—Gain in cycle efficiency with pressure ratio increase. Efficiency curve is marked with arrow to the left; duct length with arrow to right

To achieve this temperature, a preheater would have to operate at 4000 R. This does not appear feasible, thus oxygen enrichment is proposed with a smaller amount of preheat (8). An efficiency gain of 20 per cent is claimed with a capital plant increase of 10 per cent. A more complete economic analysis is obviously required on oxygen enrichment.

One of the major practical problems is the ash separation (from coal), and the seed recovery. An analysis of this problem has been performed by S. Way (11), who assumed 90 per cent ash separation in the combustor, and slightly better than 99 per cent recovery of the potassium, see Fig. 5. Way assumes that K_2SO_4 will be formed but the potassium make-up is KCl, which is 1 per cent of the fuel cost. Note that the K_2SO_4 reflux is 30 per cent of the coal! Way also considers cesium carbonate (0.1 per cent molar cesium). The reflux is reduced to 2.33 kg/sec, and the make-up cost is 4 per cent of the fuel cost (based on a 96 per cent reduction in the price of cesium carbonate), provided that an electrostatic precipitator is added to achieve a total cesium recovery of 99.95 per cent! In spite of these difficulties, Way prefers cesium because of the smaller reflux.

Closed Cycle MHD Generators

In the closed-cycle MHD generator, the same working fluid is recirculated. At present, there is no experimental data on this device. In the following section, the theoretical work is discussed, on the application of closed cycle generators, nonequilibrium ionization and generator geometries, and a-c conversion. The most promising application appears to be non-equilibrium ionization MHD generators for space power.

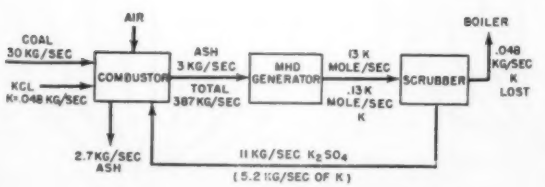

Fig. 5—Potassium cycle, coal burning MHD generator

1. Nuclear/Vehicle Power

The main advantage of a closed cycle MHD generator is that the composition and pressure of the working fluid can be selected arbitrarily. The main disadvantage is the complications involved in heating the fluid. If gaseous fission or fusion of the working fluid itself is not considered, then a heat exchanger to the energy source is required. It appears that the only justification for this complication is the use of a nuclear reactor as the energy source.

Nuclear reactors will become attractive for central station MHD power only if the efficiency is improved or if the required capital cost is decreased. Reactors currently under construction such as the HTGR has a 40 per cent efficiency at 1340 F, which is subject to considerable improvement. Thus the MHD generator must have a lower capital cost; this may be accomplished by elimination of the secondary heat exchanger and steam loop. Nuclear reactors are also attractive for vehicle power for space missions, where 1 to 20 Mw of power will be required for 2 to 4 years (12). At present, turbogenerators using liquid metals are under consideration. Their major problem is the temperature limitation: with an exhaust temperature of only 1050 F, and a conversion efficiency of 11 per cent, the radiator must have 3500 sq ft for 1 Mw (12). The limitation is mainly thermal degradation of the alternator insulation, since the alternator is usually immersed in the working fluid.

The MHD generator must also have electrical insulation, but since it is on the *outside* of the generator it can be regeneratively or radiatively cooled to lower temperatures than the MHD generator exhaust temperature. Thus higher exhaust temperatures are possible, which can reduce the radiator size by a factor of 6, (13). Clearly, efficiency is not as important as the temperature level for this application.

The major problem in the use of MHD generators with solid fuel reactors is the low temperature of the working fluid. Opinion is divided on the upper practical temperature for continuous operation of the reactor itself, but a conservative estimate is 2000 F (1370 K), while the optimistic estimate is 4000 F (2500 K). For example, a nuclear rocket engine may operate at the higher temperatures, but for short amounts of time. Even if the higher temperatures are achievable, after the gas is accelerated in the MHD generator electrical conductivity will be too low to be practical. Thus, non-equilibrium ionization is required.

2. Non-Equilibrium Ionization

There are two approaches toward obtaining non-equilibrium ionization. In the first approach, equilibrium ionization is established at stagnation conditions and then the gas is rapidly accelerated so that the electrons are "frozen" out (14). Equipment to determine the effectiveness of this method is being constructed by B. C. Lindley of C. A. Parsons, England (15). Up to 3 per cent molar cesium will be added to a 5 to 7 g/sec helium flow which has been resistance heated to 1500–2500 C. Total pressure will be varied from 0.2 to 1.2 atm. The gas mixture will be expanded in a nozzle with an expansion pressure ratio of 20, to give a Mach number of 2.3 and velocity of 3400–4300 M/sec. It will then flow into a 1.25 × 3.8 × 13 cm segmented electrode

generator having a 18 kilogauss magnetic field. Independent measurements of the electron density and conductivity are also planned. These experiments have not yet been performed, but the results will be extremely interesting.

The other approach to non-equilibrium ionization is the use of electric field ionization; that is, some form of preionization. The electric field raises the electron temperature and increases the degree of ionization (20, 21). This effect is most pronounced in monatomic gases; but in diatomic gases the electron energy is absorbed by the vibrational states. Thus, there is little likelihood for successful preionization in combustion gases.

3. Generator Geometries

To increase or sustain the non-equilibrium ionization, the closed cycle generator will probably be operated at low density. The performance will depend on the geometry which must be specified. For linear-flow generators, there are three types: continuous electrodes, segmented electrodes, and the Hall generator. They are characterized as follows (16):

1. Continuous Electrode: Axial Electric Field is zero.
2. Segmented Electrodes: Axial Current is zero.
3. Hall Generator: Transverse Current is zero.

The power density of these three (neglecting ion slip) is

$$P_1 = \frac{\sigma}{0.1 + \beta^2} U^2B^2K(1 - K)$$

$$P_2 = \sigma U^2B^2K(1 - K)$$

$$P_3 = \frac{\beta^2}{1 + \beta^2} \sigma U^2B^2K(1 - K) \qquad (1)$$

where U is the gas velocity, B is the magnetic field, σ is the scalar electrical conductivity of the gas, K is the ratio of load to open circuit voltage, and β is the ratio of the electron mean-free-path to the Larmorr radius. β generally increases with increasing magnetic field or decreasing density. In a closed cycle generator it is necessary to operate at reduced pressure to enhance the ionization or decrease the recombination time so that β will be greater than unity.

Next, the efficiencies must be considered. These are given by:

$$\eta_1 = \eta_2 = K$$

$$\eta_3 = \frac{\beta^2(1 - K)}{K^{-1} + \beta^2} \qquad (2)$$

For generators (1) and (2), the greater the value of K, the greater the efficiency. However, in generator (3), the efficiency has a maximum when:

$$K = K_{m_3} = (\sqrt{1 + \beta^2} - 1)\beta^{-2} \qquad (3)$$

and the corresponding value of the efficiency is:

$$\eta_{m_3} = 1 - 2K_{m_3} \qquad (4)$$

Obviously, large values of β are required to obtain efficiencies near unity; for large β equations (3) and (4) become:

$$K_{m_3} \doteq \frac{1}{\beta}, \quad \eta_{m_3} \doteq 1 - \frac{2}{\beta} \qquad (5)$$

Even if β is as large as 10, $\eta_{m_3} = 80$ per cent. Thus it is necessary to operate the Hall generator at peak efficiency. The advantage of the Hall generator is that it can have just two terminals. Geometry (2) can also have only two terminals if the electrodes are connected series, but then the generator can operate at only a given value of K.

Finally, we consider the power density. For large values of β, Equation (1) becomes:

$$P_3 \backsimeq \frac{\sigma U^2B^2}{\beta}$$

For the same efficiency, the segmented electrode generator will have a value of K given by:

$$K = 1 - 2K_{m_3} \doteq 1 - (2/\beta)$$

and for large values of β, equation (1) becomes

$$P_2 = \frac{2}{\beta} \sigma U^2B^2$$

Thus, for β large and the same efficiency, the power density of the segmented electrode geometry will be twice that of this Hall generator. This means that the Hall generator will be twice as long as the segmented electrode generator. This is both expensive from the viewpoint of hardware and magnetic field and, in addition, the longer length will introduce larger viscous losses.

In either the segmented electrode or Hall generator, the individual segments cannot be made infinitely small but must be finite in size. Considerable distortion of the field lines occur in such a geometry which is caused by the tensor conductivity. An analysis of this effect in which the thermal and velocity boundary layers were neglected (22) shows that the current lines tend to concentrate near the downstream edge of the electrodes as β increases, see Fig. 6. This may have an advantage in increasing the local electron emission, but it may also cause the electrodes to burn off at that point.

Another possible geometry is the vortex generator (13, 19). It has the advantage of a more compact magnetic field, but in so far as power density is concerned, it has properties similar to the continuous electrode

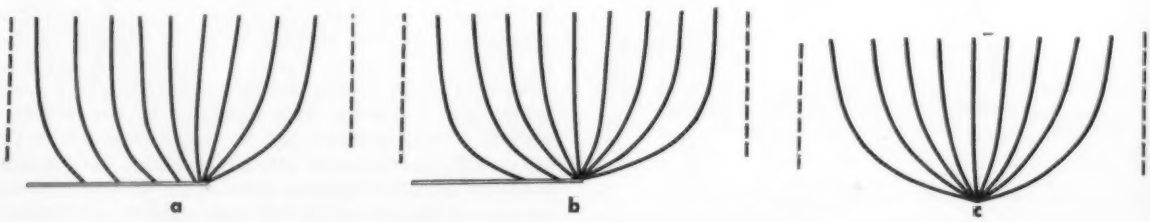

Fig. 6—Electric current lines in a segmented electrode generator, as β increases. (a) $\beta = 1$; (b) $\beta = 3$; (c) $\beta = \infty$

geometry. The power density is reduced by the Hall currents, unless operated at high pressures ($\beta < 1$) but then the ionization is reduced. The Hall currents can be remedied somewhat by increasing the ratio of the radial velocity to tangential velocity; in the limit of pure radial flow this reduces to the Hall generator.

In summary, the use of non-equilibrium ionization for use with nuclear reactors appears possible from theoretical analyses. Future experiments will determine the merits of this approach.

A-C Conversion

As a final topic we consider the direction conversion to a-c power. In general, either circuit switching or alternating the magnetic field appears very difficult. However, direct electrodeless conversion to a-c power may be possible (23, 24). This has been included under nuclear energy sources for reasons which will be obvious later.

The concept of electrodeless a-c conversion requires a sinusoidal magnetic field which travels in the flow direction at a velocity which is less than the flow velocity. This magnetic field induces currents in the flow; the magnetic field caused by these currents cuts the magnet coils and induces an emf in them. On the other hand, the interaction of the currents in the flow and the magnetic field induce a retarded Lorentz force in the flow. Thus, the flow energy is converted into electrical energy. The frequency f is given by the magnetic field velocity U_B divided by the magnetic field wave length λ:

$$f = U_B/\lambda \tag{6}$$

Now, U_B must be approximately equal to the gas velocity; a minimum value is about 10^3 M/sec. The wave length is determined by the generator length: for a long generator it could be as large as one meter. This gives a frequency of 10^3 cycles per seconds, which is too large by an order of magnitude for central station use (60 cycle). However, this value is acceptable in vehicles.

Some additional formulas are required. Let us take the flow in the z direction; the magnetic field then varies as R exp $(i2\pi z/\lambda)$ and is related to the magnet coil current J and the induced current j as follows:

$$\nabla \times \vec{\Gamma} = \frac{\partial B}{\partial z} = -\mu\left(\frac{J}{d} + j\right) \tag{7}$$

or

$$B = \frac{\mu i\lambda}{2\pi}\left[\quad + j\right] = B_0 e^{i2\pi z/\lambda} + \frac{i\lambda\mu}{2\pi} j \tag{8}$$

where a is the distance between coils and B_0 is the field in the absence of the conducting fluid and μ is the permeability. Now the induced current is given by

$$j = \sigma(E - UB) \tag{9}$$

and must be zero if the fluid velocity U is equal to the field velocity t'_B or

$$E = U_B B = KUB \tag{10}$$

and

$$j = -\sigma(U - U_B)B = -\sigma UB(1 - K) \tag{11}$$

where $K = U_B/U$ plays the same role as for the d-c generator. Thus, the efficiency $\eta = K$. Substitution of equation (11) into equation (8) yields the value of B:

$$B = \frac{B_0 e^{i2\pi z/\lambda}}{1 - iR_m} \tag{12}$$

where $R_m = 2\mu\lambda\sigma U(1 - K)$ and the real part is

$$R(B) = \frac{B_0[\cos(2\pi z/\lambda) - R_m \sin(2\pi z/\lambda)]}{1 + R_m{}^2} \tag{13}$$

and the generated power density is $P = -Ej$, which with the use of equations (10), (12), and (13) becomes:

$$P = \frac{\sigma B_0{}^2 U^2 K(1 - K)[\cos(2\pi z/\lambda) - R_m \sin(2\pi z/\lambda)_0]^2}{(1 + R_m{}^2)^2} \tag{14}$$

or, when averaged over one wave length becomes:

$$\bar{P} = \frac{B_0{}^2 UK}{2\mu\lambda}\frac{R_m}{1 + R_m{}^2} \tag{15}$$

The generated power has a maximum when $R_m = 1$; however for combustion gases, $R_m \backsimeq 0.1$. The only way to obtain R_m of one is to increase the electrical conductivity to 100–1000 ohm^{-1} M^{-1}; this may be accomplished using non-equilibrium ionization. Thus, monatomic gases must be used, which limits the application to nuclear energy sources. In addition to power considerations, the power factor, which is also the ratio of circulating magnet energy to generated power, is given by $R_m{}^{-1}$. Values of $R_m < 1$ are not practical; hence combustion gases are again not useful.

Thus, to produce useful a-c power requires a magnetic Reynolds number which is of the order of unity; this requires electrical conductivities in the non-equilibrium range, which has not yet been demonstrated. Since non-equilibrium ionization requires large values of β, the influence of the tensor conductivity must be determined.

Summary—Power

The attainment of practical MHD power is still a major challenge. Further attention must be directed toward three significant areas: larger magnetic fields, the erosion of materials in the generator, and the attainment of higher electrical conductivities.

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Editor's Note: Because the following summation so succinctly states the background for the present thinking in aircraft and missile development and represents so interesting a view of the role of the power plant in this field, we print it as it was presented.

In the field of aircraft when it was very young, aircraft were designed first, and then the power plant was designed for that aircraft. Only when the field matured was it realized that the power plant limited the aircraft performance—and after that, power plant development preceded aircraft.

In the field of rockets, the vehicle was first designed and then the power plant, even though power plant development time was longer. This trend has only recently been reversed andmust be continued.

The primary mission will be interplanetary exploration. Here, the other competing power plants are nuclear, high performance chemical, and ion drives, with the latter in the furthest state of research. The primary difference between MHD propulsion and ion propulsion is the thrust per unit area of exhaust. For propulsion devices larger than a megawatt, the advantage will probably be with the MHD accelerator. However, for the entire spectrum of thrust levels, only adequate research will tell.

New Record Set for World's Largest Turbine

Consolidated Edison Company of New York has ordered the world's largest steam turbine-generator unit from Allis-Chalmers.

The new unit is expected to generate in excess of one million kilowatts of power, Harland C. Forbes, chairman of Con Edison said in announcing the order. It will be part of a 131 million dollar generating facility adjacent to the utility's East River Station here.

Shipment of components of the steam turbine-generator from the Allis-Chalmers plant in Milwaukee is scheduled to begin in 1964.

Forbes said recent developments in technology have made machines of that size feasible for utility systems large enough to absorb the great blocks of power the machines represent. Units of that size also provide substantial investment savings per kilowatt of capacity.

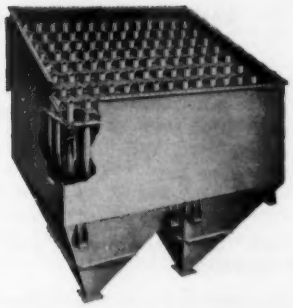
The huge turbine-generator will be of cross-compound design. The turbine wil have five sections: one high pressure, one intermediate pressure and three low pressure. The high and intermediate pressure sections will be coupled in tandem to drive one of the two fully supercharged, hydrogen cooled generators at 3600 rpm.

The three low pressure turbine sections will be coupled in tandem to drive the other generator at 1800 rpm.

Steam will be supplied to the high pressure turbine at a pressure of 2400 pounds per square inch and temperature of 1000 degrees F. After going through the high pressure section, the steam will return to the boiler for reheat to 1000 degrees before entering the intermediate turbine section and continuing through the three low pressure sections.

The new unit scheduled for operation in 1966 is the third large steam turbine-generator unit ordered from Allis-Chalmers by Con Edison since 1957. In March of this year, the first of these—with a capacity of 410,000 kilowatts—was placed in service at the utility's Astoria Station on Long Island. Early in 1962, a twin machine will be placed in operation at the same station.

TWO COST-SAVING ADVANTAGES OF CYCLO-TRELL MECHANICAL DUST COLLECTOR



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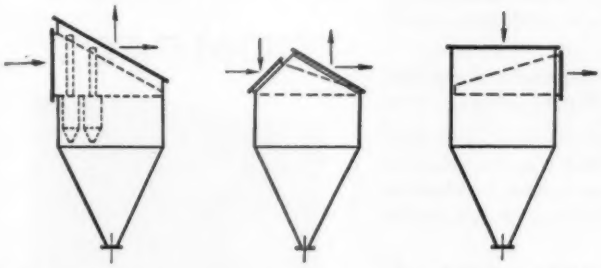

Most installations are engineered with a combination of these Cyclo-trell designs.

Whenever an installation requires a configuration different from the standard types shown, Research-Cottrell draws on its 49 years of gas cleaning experience in designing a custom-built unit. These custom units may be of the multiple tube or involute design, and are for power, cement, coal drying, chemical, petroleum, mining, quarrying, metals industry, or other applications.

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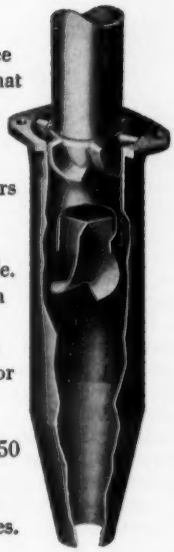

Actual operating experience in the field has proven that Research-Cottrell tubes last longer.

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Abstracts from the Technical Press—Abroad and Domestic

(Drawn from the Monthly Technical Bulletin, International Combustion, Ltd., London, W. C. 1)

Fuels: Sources, Properties and Preparation

Liberation of Pyrite from Steam Coals. R. A. Glen and R. D. Harris. *Amer. Power Conf. Paper* 1961, (Mar.), 26 pp.

Research into the possibilities of reducing the S content of coals of high S content has shown that the major portion of the pyrite exists as particles large enough to be separated after liberation. The major portion is associated with the mineral matter and can be separated by coarse pulverizing. The microscopic particles embedded in the coal substance tend to concentrate in the fine fractions below −200 mesh and further research is required into separating techniques for these small fractions.

The Oxidation of Bituminous Coals during Storage and its Prevention. W. Radmacher and A. Hoverath. *Brennst Chemie* 1961, **42** (Apr.), 97–108 (in German).

The investigations have shown that in the storage of: (1) large coals, the danger of autoignition is very small since the air passing through cools the coal below the ignition point; (2) small coals, autoignition may occur but rarely does the oxidation proceed to the point of ignition; boreholes to increase ventilation are recommended where the rise of temperature appears dangerous; (3) fine, uncompacted coals are most liable to autoignition but the maximum autoignition temperature can be forecast by measurement of gas composition and temperature; (4) fine, compacted coal is not liable to autoignition because of the lack of oxygen. Changes in the caking and coking properties of these coals can be slowed up by compaction.

Modern Ore and Coal Handling Installation in the Amsterdam West Harbour. W. Golawski. *Fördern und Heben* 1961, (*Special Hanover Fair Edition*), 183–91.

A split stockyard served by a conveyor bridge for stocking and a grab-equipped transporter for reclaiming has been added to the earlier installation. This permits the simultaneous loading and unloading of ocean-going ships and barges, railway wagons or lorries. A shuttle platform allows both transporters to work on one or the other side of the stockyard or separately. The stockyard area allows the storage of several million tons of ore and coal and can be further extended if required later on. The description includes the conveyor and transporter, transfer and return stations, hopper and tripper cars and the control system which requires only two operators.

Potomic Electric Spends $195 Million to Meet Rapid Rise in Power Demand. Anon. *Link-Belt News* 1961, **28** (Jan./Feb.), 1–3.

The coal handling at Dickerson power station containing two 185 MW units is described. It consists of a rotary car damper (1 car every 3 min.) discharging into a track hopper, two 54 in. conveyor belts to the crusher house (750 t/h capacity), the crusher house with a breaker reducing coal to minus $1^1/_2$ and a sampler, a 54 in. conveyor discharging either to the power plant conveyor or to a stocking out stationary boom conveyor.

Coal Handling Trials with Special-purpose Dozer Blades. Anon. *Mech. Handl.* 1961, **48** (May), 270–1.

Stocking out and reclaiming tests with a specially designed blade of U-shape were carried out at Brighton "B" power station and the results are tabulated.

Air Panels Keep $^1/_4$-in. × 0 Coal Moving in Bunker. R. J. Brandon. *Elect. Wrld.* 1961, **155** (Apr. 24), 78.

Inflatable neoprene panels have been installed in the bunkers of St. Clair Power plant to prevent sticking, hanging-up and arching of the coal and were found in excellent conditions after a whole year's service. Six panels are installed on the sloping sides of each bunker and operated sequentially and continuously as long as the drag feeder below the bunker is working.

Heat: Cycles and Transmission

Thermodynamics. J. M. Smith. *Ind. Engng. Chem.* 1961, **53** (Apr.), 315–8.

The annual review of literature published during 1960.

Effect of the Rate of Circulation on the Coefficient of Heat Emission on Boiling in Tubes. S. S. Kutateladze. *Energomashinostroenie* 1961, **7** (Jan.), 12–15 (in Russian).

A simple interpolated formula for calculating the joint effect of forced convection and the evaporation process on the intensity of heat emission is suggested. *C.E.G.B. abstract.*

Steam Generation and Power Production

Phase Transition in the Supercritical Region and the Inversion Curve. D. D. Kalafati. *Teploenergetika* 1961, **8** (Jan.), 72–8 (in Russian).

The conditions of phase transition in the supercritical region are considered, the inversion curve of real gases and the line of maxima of the derivative are examined. The combined analysis of lines of phase transition and the inversion curve are discussed. Twenty references are given. *C.E.G.B. abstract.*

Steam Generators. K. Cleve. *B.W.K.* 1961, **13** (Apr.), 163–4 (in German).

The largest boilers being built at present have a capacity of 500 t/h with steam temperatures rarely exceeding 535 C. Natural circulation boilers have design steam pressures up

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The Design of Steam Boilers with Stagewise Evaporation. J. Jackson. *Brit. Pwr. Engng.* 1961, **2** (May), 29–33.

This is a translation from the Russian of parts of a book entitled "Modern Boiler Units" giving the reasons for the introduction of this system of steam generation and some examples of recent developments.

A Pre-Engineered Standard Steam Generator Series. D. A. Cassino. *Heat Engng.* 1961, **36** (Jan./Feb.), 8–11.

Four standard series of water-tube boilers are described: (1) SC contains 12 sizes of liquid or gaseous fuel fired boilers up to 200 klb/h, 1500 psi and 900 F; (2) SD consists of 8 sizes up to 500 klb/h, 1500 psi and 950 F, also oil or gas fired; (3) SE of 10 sizes of pulverized coal-fired boilers up to 200 klb/h at 1500 psi and 900 F; (4) SF with 8 sizes up to 500 klb/h, 1500 psi and 950 F, also pulverized coal fired.

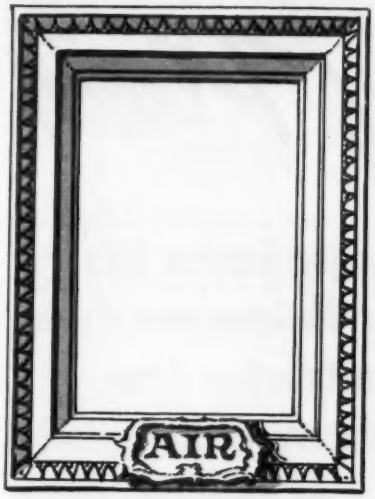
The Removal of Silicic Acid from New Boilers. T. Samuel. *Mitt. V.G.B.* No. 71 1961, (Apr.), 104–8 (in German).

Tests on a new experimental boiler of the Centre Belge d'Etude et de Documentation des Eaux (CEBEDEAU) have shown alkaline treatment with various hydroxides and phosphates did not result in a rapid removal of SiO_2 but acid treatment was very effective. Thorough flushing of the boiler after acid treatment is imperative to remove any remaining traces of SiO_2. The SiO_2 content of boiler water is a function of pressure and heat release rate. The distribution coefficients of SiO_2 in the water and steam were 30–40 per cent lower than those in the published literature.

Solid Fuel Firing

Bituminous Coal Firing. A. Sifrin. *B.W.K.* 1961, **13** (Apr.), 165–6 (in German).

About 86 per cent of all boilers above 100 t/h ordered in Germany in 1960 had slagging furnaces, those above 400 t/h exclusively slagging furnaces. New burners have been developed with fewer but higher velocity secondary air jets to obtain better mixing and combustion, the velocity being kept constant at all loads. Burners are now also available for firing a wide variety of coals. About 16 per cent of all boilers ordered can be fired by coal and oil simultaneously or separately.



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Brown Coal Firing. A. Frenzke. *B.W.K.* 1961, **13** (Apr.), 166–8 (in German).

Little change is reported in the design of boilers and burners, but in mills there is a trend toward those without classifiers and burning out grates under the furnace hoppers. A new beater mill with increased output and reduced wear by improvement of the axial suction design has been developed and proved highly successful.

Further Development of Burners for the Vertical Cyclone. H. Hülsmeyer. *Mitt. V.G.B.* No. 71 1961, (Apr.), 128–30 (in German).

The original burner design having proved unsatisfactory mainly because of the multiple subdivision of the secondary air and the resulting existence of points of excess and deficiency of air various changes of design were tried out. In the first, air ports with pivoted dampers were arranged at the side of each burner which was also provided with mantle air; the effect of the pivoted dampers was thus small. In the second, burners and secondary air ports were both arranged tangentially but the ignition delay caused considerable erosion of furnace tubes. In the third, the burners of the two mills were arranged not vertically as before but side by side and in the direction of a secant to the tangentially arranged secondary air ports so that the secondary air meets the coal about 1 m behind the exit. This has led to a uniform furnace atmosphere, a dew point of the flue gas of about 113 F, low load operation down to 35 per cent of full load, increased ash retention and reduced wear and warping of burners and air nozzles. The burning of coke with a temperature of 1,560–1,650 F had to be abandoned because of excessive tube erosion.

Liquid and Gaseous Fuel Firing

Oil Firing. T. Geissler. *B.W.K.* 1961, **13** (Apr.), 168–70 (in German).

Despite the introduction of a fuel oil tax in Germany in 1960 the consumption has increased by 30 per cent. Boilers fired with oil only rarely exceed 100 t/h but in many boilers oil firing has been added to support ignition of low grade fuels. Means against high-temperature corrosion by V_2O_5 have not been found but against low-temperature corrosion magnesite has proved superior to dolomite.

Furnaces and Combustion

Advances in Combustion. M. W. Thring. *Brit. Pwr. Engng.* 1961, **2** (May), 24–8.

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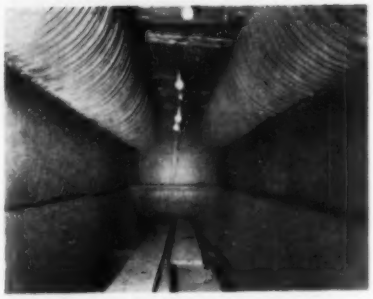

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willingness of British industry to support research and exploit its findings and citing various examples (Benson and La Mont boilers, e.g.) lines of development for coal burning in domestic, central-heating and small industrial appliances, kilns, pulverized coal fired furnaces and cyclone furnaces, oil and gas firing are outlined. Improvements in steel and iron making based on recent research are described. Possibilities of direct electricity generation are discussed.

Preventing Furnace Explosions. Pt. 3. W. L. Livingston and P. Gray. *Amer. Power Conf. Paper* 1961, (Mar.), 9 pp.

A practical protection philosophy is presented which describes and defines the unique service ideal flame detection can provide. The general application of presently available flame sensors and their relationship to this ideal is discussed.

Water-Side Corrosion and Water Treatment

New Clues in the Boiler Tube Pitting Puzzle. F. E. Clarke and A. J. Ristaino. *1st Internat. Congr. Met. Corros. Paper No. Y*, London 1961, (Apr.), 129–33.

Remarkably similar boiler pits can result from entirely different corrosion mechanisms. Dissolved air pitting is confined primarily to heavily aerated condensing systems and idle boilers. High temperature chemical pitting that requires no free oxygen appears to predominate in steaming boilers. No known practicable chemical treatment will control corrosion adequately in a cold partially filled boiler. Alkaline phosphate solution localizes attack, the extent of damage increasing with increase in chloride ion content. Sodium sulfite treatment is better since it prevents pitting of submerged areas and yields sodium sulfate which tends to inhibit caustic attack under sludges. The effect of dissolved oxygen in steaming boilers probably is small, but has not yet been thoroughly assessed.
From C.E.G.B. Digest 1961, **13** (May 13), 1348.

Behavior of Stainless Steels and Other Engineering Alloys in Hot Ammonia Atmospheres. J. J. Moran, J. R. Mihalisin and E. N. Skinner. *Corrosion* 1961, **17** (Apr.), 115–9.

Nickel-base alloys were more resistant to nitrogen attack than alloy richer in iron and chromium.

Composition of Corrosion Products Formed on Metals in Steam Condensate. R. D. Eberhardt, E. W. Arneson and C. E. Imhoff. *Corrosion* 1961, **17** (Apr.), 95–6.

Corrosion of carbon steel, cast iron, Admiralty metal, Muntz metal, aluminum 35 and zinc in condensate with a pH of 5.1 to 9.6 and temperatures of 100 and 212 F was studied. On steel and cast iron magnetite and basic ferric oxides formed, on Admiralty and Muntz metal cuprite at a pH of 6 or below, on zinc oxides over the whole pH range.

Corrosion of Metals by Weak Acids under Heat Transfer Conditions. N. D. Groves, C. M. Eisenbrown and L. R. Scharfstein. *Corrosion* 1961, **17** (Apr.), 97–100.

Various stainless steels, Inconel and Monel were exposed to acids differing in concentration at temperatures between 230 and 284 F. Carpenter No. 20-Cb and Hastelloy were most resistant, Monel's resistance decreased with increasing temperature.

Operational Experience with Hydrazine Hydrate in a Steam Power Station. G. Gutperle. *Mitt. V.G.B.* No. 71 1961, (Apr.), 136–7 (in German).

Since the introduction of hydrazine the contents of iron and copper in the condensate have been much reduced, corrosion on feed pumps and feed heaters has ceased, deposits on tubes and slurry in the drums do no longer occur so that it is not necessary to use blow-down. In consequence make-up required has been reduced to 1 per cent. If the boilers are to be stopped for up to 30 h the N_2H_4 injection is increased to 0.7–0.8 mg/l, for longer periods to 10–15 mg/l with subsequent addition and circulation of the water to keep up a N_2H_4 excess. The savings have far exceeded the cost of the N_2H_4.

The Use of Condensed Phosphates as Protection against Corrosion and Scale Formation in Hot Water Pipelines. E. Herre. *Mitt. V.G.B.* No. 71 1961, (Apr.), 90–8 (in German).

Tests with a number of condensed phosphates have shown that disodium phosphate, tripolyphosphate, hexametaphosphate and their mixtures form a fast adhering, nonporous protective layer provided that the water temperature does not exceed 75 C (167 F), formation of air bubbles is avoided and the pipelines are not corroded already. The admixture of metasilicates is not recommended.

Gas-Side Corrosion and Deposits

How Coal Properties relate to Corrosion of High Temperature Boiler Surfaces. J. T. Reese, J. Jonakin and J. G. Koopman. *Amer. Power Conf. Paper* 1961, (Mar.), 5 pp.

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Tests of five boilers of identical design and operating conditions with 5 different coals using corrosion probes have shown that water-soluble alkalis and their molar ratio are the only coal properties which appear to be critical factors in deposit-type corrosion.

Elevated Temperature Corrosion of Type 310 Stainless Steel by Vanadium Compounds. H. L. Logan. *Corrosion* 1961, **17** (Apr.), 109–11.

Catastrophic attack by a mixture of 67 wt. per cent V_2O_5 + 33 wt. per cent of $NaVO_3$ occurred at temperatures of 1900–2000 F if the steel had previously been oxidized and air and water vapor were present. An investigation of the slag suggests that nickel is selectively absorbed by the slag prior to the general attack.

Power Generation and Power Plant

District Heating and Heat Power Stations. F. H. Ebert. *B.W.K.* 1961, **13** (Apr.), 159–61 (in German).

Demand for supply of heat by district heating continues to increase in Germany and several new combined heat and power stations are commissioned, under construction or planned. In the Oberhausen heat power station a coal fired hot air turbine has been started up, near Hanover an extraction-condensing station is being built to supply heat to the whole inner part of the town, in Mannheim and network is being enlarged to supply more customers and in Munich a large plant is under construction to supply an industrial area, new suburb and hospitals containing natural gas fired turbines with heat exchangers and waste heat boilers. Near Cologne a plant for supplying heat to a new suburb is to be fired with pulverized coal supplied in tank wagons. In several towns refuse burning plants are being planned in conjunction with district heating.

Initial Operation of Avon No. 8. A Supercritical Plant. N. F. Gill and N. D. Flack. *Amer. Power Conf. Paper* 1961, (Mar.), 21 pp.

Performance availability, problems encountered and solved and findings during a complete overhaul are described. The economics of a supercritical unit are compared with that of a subcritical unit.

Supercritical Boiler Operating Experience at Avon No. 8. J. I. Argersinger and G. C. Smith. *Amer. Power Conf. Paper* 1961, (Mar.), 15 pp.

The description includes: (1) boiler design and operation; (2) boiler construction; (3) performance; (4) problems; (5) special components; (6) controls.

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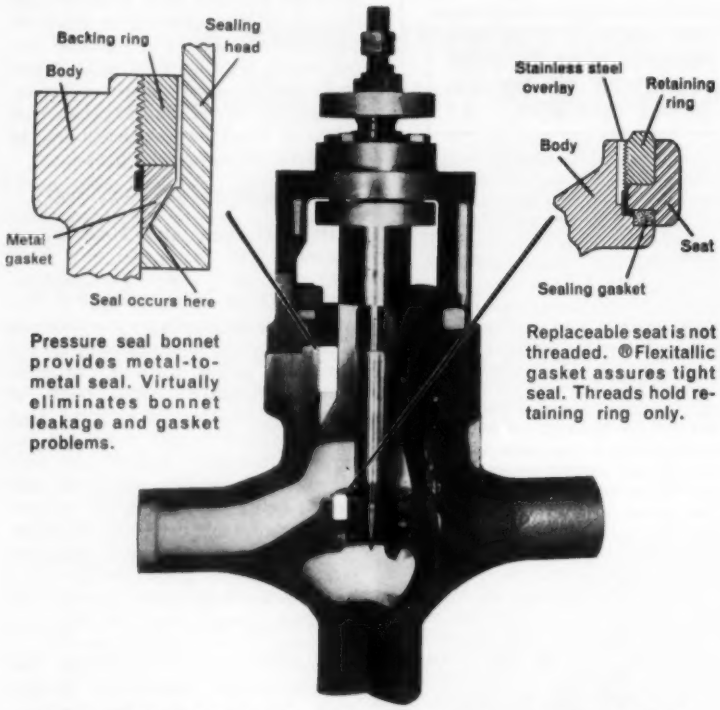

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Avon Superpressure Steam Turbine Generator Unit. C. C. Franck and J. A. Carlson. *Amer. Power Conf. Paper* 1961, (Mar.), 18 pp.

The design of this 250 Mw unit operating at 22 kv, 0.85 p.f. and 45 psi hydrogen pressure with internal cooling of the stator through vent tubes and the rotor through the conductors is described. The turbine control system, starting procedure and loading procedure are outlined. A few problems which occurred during operation are discussed.

The Water and Steam Circuits of the Reheat Boiler-Turbine Unit at the Drogenbos P/S., Belgium. M. Schouls and F. Decelle. *Votre Electricité* 1961, **32** (Feb.), 21–32 (in French).

Results are given of observations made during four years operation of the Babcock and Wilcox 210 t/h, 1500 p.s.i.g., 1000 F (reheat 985 F) p.f.f. boiler and the Brown Boveri 62 Mw reheat turbine. The method, developed over a number of years for low-pressure units, of feeding very pure untreated water without the addition of hydrazine or morpholine has been applied to the reheat unit. Make-up water is obtained from blowdown from the m.p. and h.p. sections. *C.E.G.B. Digest* 1961, **13** (May 27), 1505.

Ellund. Anon. *Elect. Rev.* 1961, **168** (May 5), 783–5.

This station recently commissioned officially contains 3 units of 60 Mw output and as an overall efficiency of 30.17 per cent and a cost of electricity sent out of 0.407 d/k wh. The boiler of one unit is of two-drum design with corner-fired furnace and tilting burners for superheat control, the boilers of the other two units have a single drum, burners in the front wall and superheat control by dampers regulating the flow of flue gas over the primary superheater. All three boilers are also provided with spray desuperheaters for final steam temperature control. Steam conditions at t.s.v. are 900 psi and 900 F. Furnace hopper and fly ash are removed hydraulically. Condenser cooling water is either provided by the river Calder or by 2 cooling towers. The turbines are of the 2-cylinder type, the generators hydrogen cooled at 15 psi.

Ground Broken for APS 350 MW Plant. Anon. *Elect. Wrld.* 1961, **155** (Apr. 10), 38.

The Four Corners plant of the Arizona Public Service Co. is located on a coal field in the Navajo reservation and will contain two units each of a boiler rated at 1270 klb/h at 1925 psi and 1005 F and a 175 Mw turbo-

generator. Fuel consumption will be 4200 t/day. An artificial lake of 1200 acre will supply condenser cooling water. The station is to be commissioned in 1963.

Expansion at Oak Creek. F. M. Barton. *Heat Engng.* 1961, **36** (Jan./Feb.), 2–7.

Unit 5 of the Oak Creel station of Wisconsin Electric Power Co. is rated at 275 Mw and served by a boiler of 1780 klb/h output at 2425 psi and 1050/1000 F with feedwater at 488 F. The furnace is L-shaped with 16 intervane burners in the roof of the horizontal part of the L served by two ball mill pulverizers; the single furnace is divided into four cells by water-cooled division walls. The all-radiant reheater constitutes furnace side and rear walls, the radiant superheater part of the rear wall and the division walls, the convection superheater of the pendant type being installed in the transition pass, while the second pass contains boiler convection surfaces. The economizer, boiler and convection superheater are supported at the top and expand downwards, the waterwalls, radiant superheater and reheater are anchored at the bottom and expand upwards, being kept in tension by springs.

Materials and Manufacturing Processes

Choice of Materials for Service at High Pressures. A. V. Ratner and L. G. Leonova. *Teploenergetika* 1960, **7** (Dec.), 14–8 (in Russian).

The article is concerned with the choice of materials for the component parts of accessories for service at high pressures and super pressures, and subject to wear. The results are given of an investigation of materials provided with different forms of hardening (boriding, nitriding, sulphiding) and also metals built-up with hard alloys. The use of one or other form is recommended for accessory flaps and spindles. Ten references are given. (A.E.I. abstract).

From C.E.G.B. Digest 1961, **13** (May 13), 1340.

Stresses in Steam Lines for High Operating Conditions. D. P. Elizarov. *Teploenergetika* 1960, **7** (Dec.), 19–23 (in Russian).

A new method is presented for the experimental determination of mechanical stresses in the walls of steam piping of pearlitic steel during the warming up process and under service conditions, and also the distribution of the stresses set up in the line. (*A.E.I. abstract*).

From C.E.G.B. Digest 1961, **13** (May 13), 1338.

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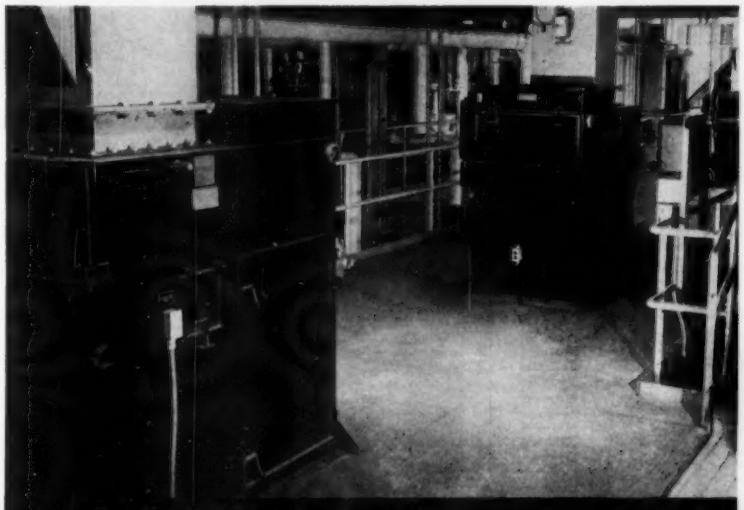

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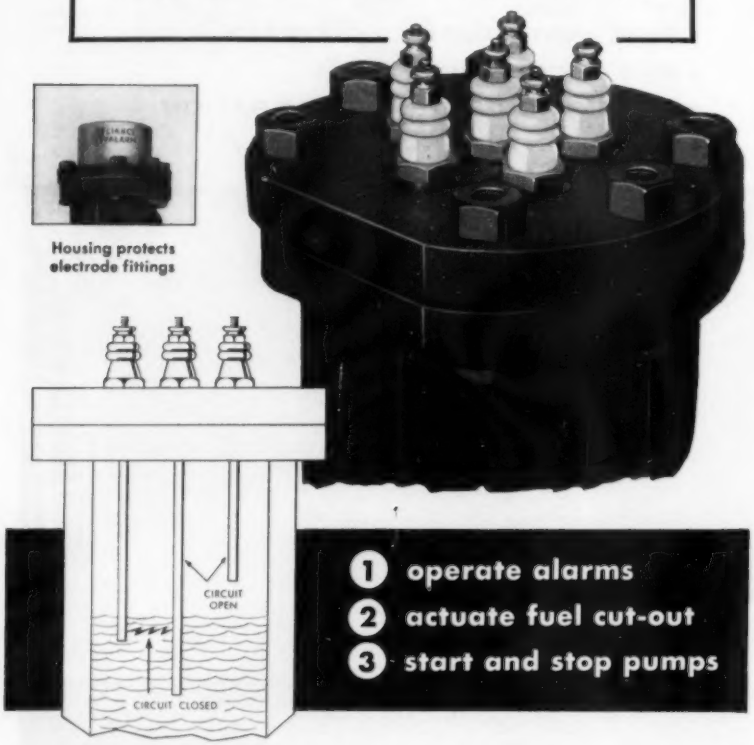

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Advertisers' Index

Air Preheater Corporation, The 6
Anaconda American Brass Company ..... *
Allegheny Ludlum Steel Corporation ..... *

Bailey Meter Company 2
Bayer Company, The 34
Bell & Zoller Coal Company .. *
Bird-Archer Company ..... *
Buell Engineering Company, Inc. ..... *
Buffalo Forge Company 3

Cambridge Instrument Company ..... *
Clarage Fan Company ..... *
Combustion Engineering, Inc. ..... Second Cover, 18 and 19
Compact Controls Company, Inc. 52
Cooper-Bessemer ..... 16 and 17
Copes-Vulcan Div., Blaw-Knox Company ..... 8 and 9
Croll Reynolds Engineering Co., Inc. ..... *

Dearborn Chemical Company .. *
Diamond Power Specialty Corporation ..... *
Dow Industrial Service, Div. of The Dow Chemical Company ..... Fourth Cover

Eastern Gas & Fuel Associates. *
Edward Valves, Inc. ..... 14 and 15

Fairmount Chemical Company. *
Foxboro Company, The ..... *

General Controls Company ... *
Graver Water Conditioning Company ..... *
Grinnell Company 28

Hagan Chemicals & Controls, Inc. ..... *
Haskins Turner Company 34

(Continued on page 60)

Illinois Water Treatment Co... 55
Industrial Instruments Inc..... *
Ingersoll-Rand Company..... *

Johns-Manville..... *

Koppers Co..... *

Leeds & Northrup Company..
.....10 and 11

Manning, Maxwell & Moore, Inc..... *
Minneapolis-Honeywell..... *
W. K. Mitchell & Company... 13

Nalco Chemical Company.... 7

Pennsylvania Crusher Div., Bath Iron Works Corp..... *
Pfaudler Permutit Inc..... 59
Powell Valves..... 20

Refractory & Insulation Corporation..... 54
Reliance Gauge Column Company, The..... 58
Reliance Instrument, Div. of Electro-Mech. Corp..... 53
Republic Flow Meters Company..... 56
Republic Steel Corporation...
.....42 and 43
Research-Cottrell, Inc..... 51
Richardson Scale Company... 57
Richardsons, Westgarth & Co. Limited..... 4
Rohm & Haas Company..... *

Standard Tube Co., The..... 60
Stock Equipment Company... *
Sumco Engineering, Inc..... *

Valley Camp Coal Company.. *
.....Third Cover

John Wood Company..... *
Worthington Corp..... *

Yarnall-Waring Company.... 5
Yuba Consolidated Industries, Inc..... 12

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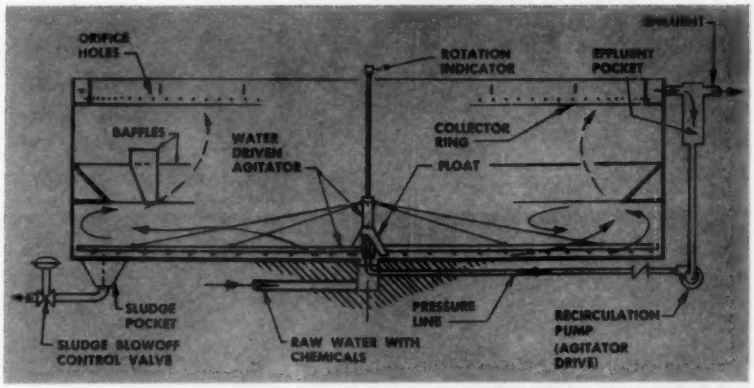

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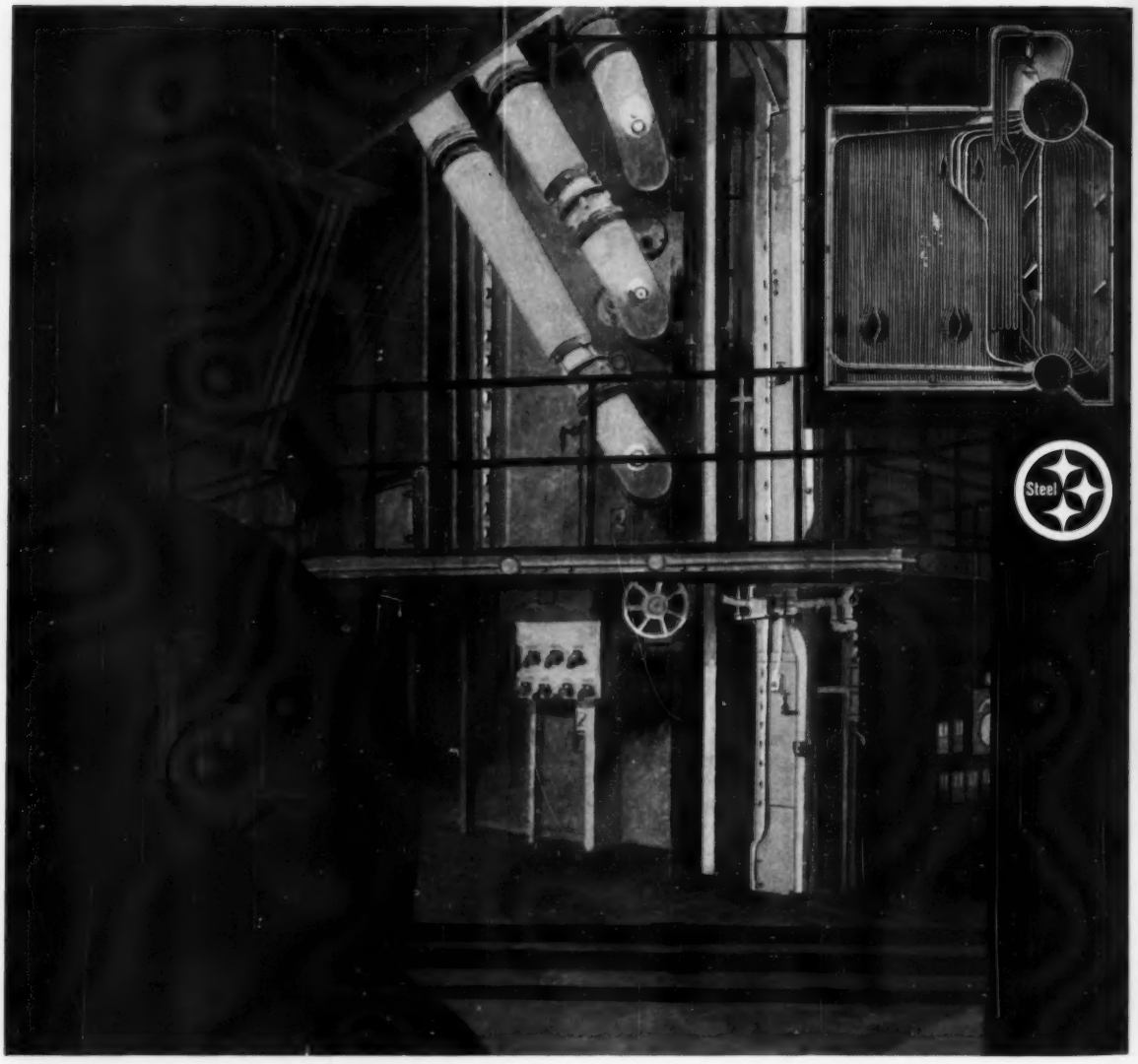

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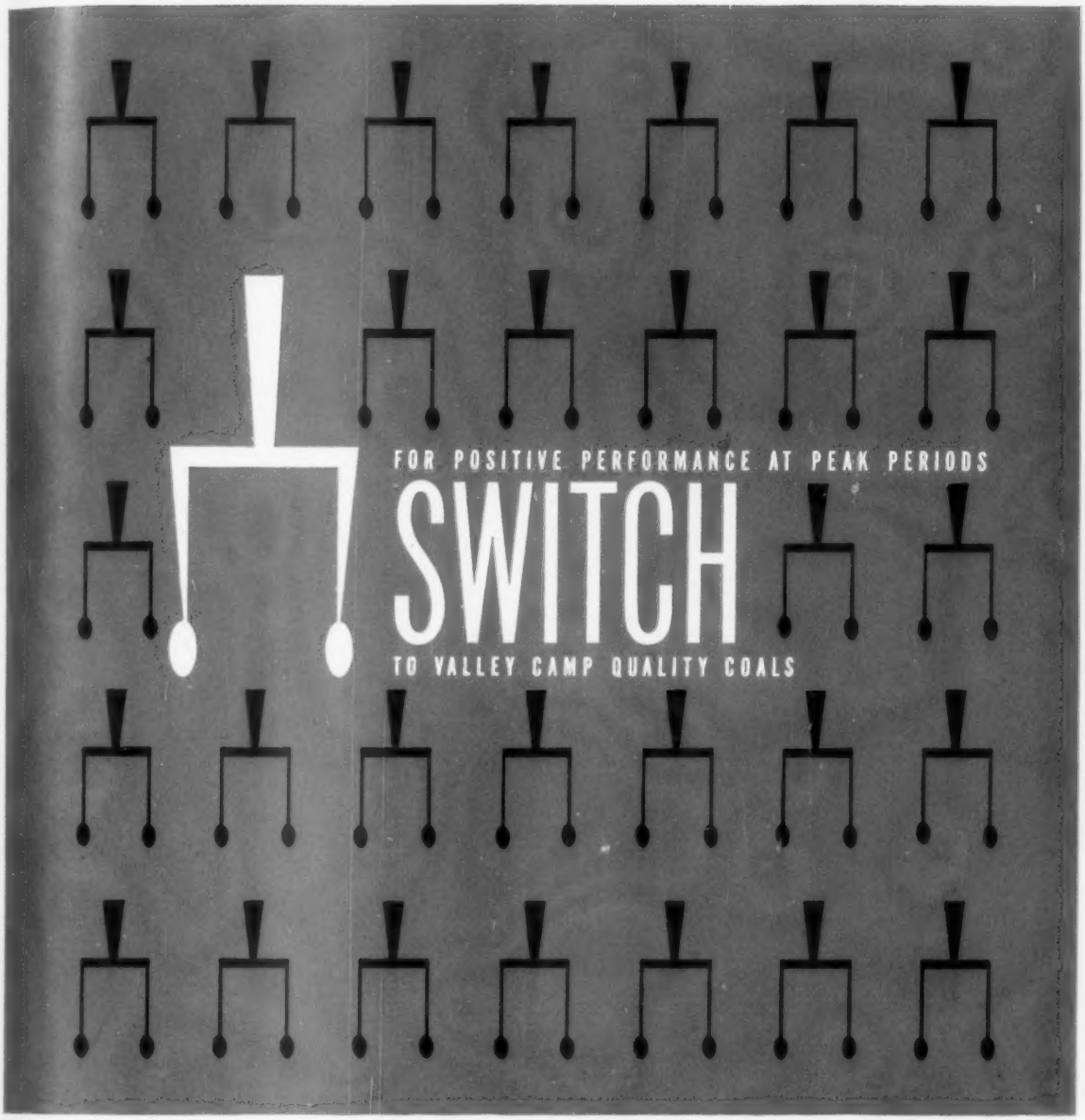

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